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OTHER WORLDS THAN OURS

THE PLURALITY OF WORLDS

STUDIED UNDER THE LIGHT OF SCIENTIFIC

RESEARCHES

BY

RICHARD A. PROCTOR

'Not to this evanescent speck of earth
Poorly confined—the radiant tracts on high
Are our exalted range; intent to gaze
Creation through, and from that full complex
Of never-ending wonders, to conceive
Of the Sole Being right'

Thomson

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FROM THE

PREFACE TO THE FOURTH EDITION.

THIS EDITION has been carefully revised, and in many important respects modified.

Several passages relating to questions which were under controversy when the earlier editions appeared have been removed,—those questions having been decided by new evidence, in the sense advocated in the original text.

I have also omitted several passages from the last chapter, as expressing a more confident opinion about matters connected with the supervision and control of the universe than I at present entertain.

RICHARD A. PROCTOR.

FROM THE

PREFACE TO THE SECOND EDITION.

AMONG the additions which have been made to the matter contained in a former edition are two which require some notice.

The first consists of new evidence against the theory that the cloud-belts of Jupiter and Saturn are raised by the sun's heat. I find it difficult to conceive how this evidence can be interpreted otherwise than by the theory that the belts of the giant planets are generated, maintained, and modified by forces inherent in those planets, and not by any action exerted from without.

The second is the matter contained in pp. 264, 265, 274–279, and illustrated by the large plate facing p. 275. Rightly understood, the evidence there presented is conclusive in favour of the two theses, that—

1. *Within the limits which include the stars visible to the naked eye there are laws of aggregation and segregation which the theories hitherto accepted respecting the fixed stars wholly fail to account for.*

2. *The Milky Way is not, as has been so long supposed, a stratum of stars of all orders extending to distances very far exceeding, relatively as well as positively, the distances of the lucid stars,—but is a stream of small stars, amidst which many of the lucid stars are immersed.* These points seem to be as completely demonstrated by the evidence adduced as relations of the sort can ever be.

RICHARD A. PROCTOR.

LONDON: *October* 1870.

EXTRACTS FROM THE

PREFACE TO THE FIRST EDITION.

On many of the subjects dealt with in this work, I have propounded views which differ from those usually accepted. Each of the new views here presented has been the result of a careful study of the subject dealt with, and I have searched as anxiously for considerations opposed to any novel theory, as for arguments in its favour.

My theory respecting the sidereal system has been based on the signs of systematic aggregation among the lucid stars, and of a more intimate association of those stars with the Milky Way than could be expected were Sir William Herschel's fundamental theory correct.

The theory brought forward in the chapter on Meteors and Comets is not altogether new. The general idea on which it is grounded has been dealt

with by Mayer and Thomson. The idea, however, presented itself independently to my mind when I was writing my treatise on Saturn. The line of reasoning is wholly new, I believe, by which I have endeavoured to show that those peculiarities of the solar system which have hitherto been regarded as affording the strongest objection to the hypothesis of development, may be regarded as in reality the direct result of the processes by which the solar system has reached its present condition. In the preface to my treatise on Saturn I touched on the possibility that some such explanation of those peculiarities might be found, remarking that in the rings of Saturn astronomers may one day recognise the action of the processes by which the solar system has attained its present state.

RICHARD A. PROCTOR.

LONDON: *May* 1870.

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INTRODUCTION.

ASTRONOMY and GEOLOGY owe much of their charm to the fact that they suggest thoughts of other forms of life than those with which we are familiar. Geology teaches us of days when this earth was peopled with strange creatures such as now are not found upon its surface. We turn our thoughts to the epochs when those monsters throve and multiplied, and picture to ourselves the appearance which our earth then presented. Strange forms of vegetation clothe the scene which the mind's eye dwells upon. The air is heavier laden with moisture to nourish the abundant flora; hideous reptiles crawl over their slimy domain, battling with each other or with the denizens of the forest; huge bat-like creatures sweep through the dusky twilight which constituted the primeval day; weird monsters pursue their prey amid the ocean depths: and we forget, as we dwell upon the strange forms which existed in those long past ages, that the scene

now presented by the earth is no less wonderful, and that the records of our time may perhaps seem one day as perplexing as we now find those of the geological eras.

Astronomy has a kindred charm. We cannot indeed examine the actual substance of living creatures existing upon other celestial bodies; we cannot picture to ourselves their appearance or qualities; and only in a few instances can we even form any conception of the conditions under which they live. But we see proofs on all sides that, besides the world on which we live, other worlds exist as well cared for and as nobly planned. Nay, we see globes by the side of which our earth would seem but as a tiny speck; we trace these globes as they sweep with stately motion on their appointed courses; we watch the return of day on the broad expanse of their surface; and we see systems of satellites which are suspended as lights for their nocturnal skies. We further find that our sun is matched by a thousand thousand suns amid the immeasurable depths of space; and the mind's eye pictures other worlds like those which course around the sun, travelling in stately orbits around his fellow luminaries.

Long, however, before the wonders of modern astronomy had been revealed to us, men of inquiring minds seem to have been led, as by an irresistible instinct, to examine into the resemblance which may exist between our world and other worlds surrounding it on every side. It has not been the mere fanciful theoriser who has discussed such questions, but men of the highest

eminence in science. In long past ages Anaximander and Pythagoras studied the subject of other worlds than ours; later, such men as Huyghens, Galileo, and Newton have dwelt upon the same interesting theme; while, in our own day, Whewell and Brewster have employed their scientific and dialectic skill in defending rival theories upon the subject.

Undoubtedly, a large share of the interest with which the question of other worlds than ours has been regarded is due to the fact that, as the science of astronomy has progressed, the subject has continually presented itself under new aspects. The question, in fact, is one of those which are ever new and ever old. It has all the charm belonging to subjects which men in all ages have delighted to discuss, while it is associated in the most intimate manner with the progress of modern scientific research. The discoveries which are made by astronomers acquire a new interest when they are associated with the subject of life in other worlds. The interest with which the public regard many of those discoveries may, indeed, be said to depend wholly on their bearing upon this subject.

We stand in a position much more favourable for the formation of just views on the subject of life in other worlds than that from which men surveyed the planetary and stellar systems thirty or forty years since. Never, since men first explored the celestial depths, has a series of more startling discoveries rewarded the labours of astronomers and physicists than during the past few years. Unhoped-for revelations

have been made on every side. Analogies the most interesting have brought the distant orbs of heaven into close relationship with our own earth or with the central luminary of the planetary scheme. And a lesson has been taught us which bears even more significantly on our views respecting the existence of other worlds: we have learned to recognise within the solar system, and within the wondrous galaxy of which our sun is a constituent orb, a variety of structure and a complexity of detail, of which but a few years ago astronomers had formed but the most inadequate conceptions.

My object, then, in the pages which follow, is not solely to establish the thesis that there are other worlds than ours, but to present, in a new and, I hope, interesting light the marvellous discoveries which have rewarded recent scientific researches. Judged merely according to their direct significance, these discoveries are full of interest. But it is when we consider them in their relation to the existence of other worlds, when we attempt to form a conception of the immense varieties of the forms of life corresponding to the innumerable varieties of cosmical structure disclosed by modern researches, that we recognise their full significance. Although the growth of our knowledge is ever accompanied by a proportional growth of our estimate of the unknown, we seem already entitled to say that we have

> Come on that which is, and caught
> The deep pulsations of the world,
> Æonian music, measuring out
> The steps of time

CHAPTER I.

WHAT OUR EARTH TEACHES US.

BEFORE proceeding to consider the various circumstances under which the worlds or systems which surround us appear to subsist, it may be well to inquire how far we have reason to conclude, from the consideration of our own earth, that other orbs in space support life.

It would not be just to argue directly from the fact that the earth is inhabited to the conclusion that the other planets are inhabited also, nor thence to the conclusion that other stars have, like our sun, their attendant worlds, peopled with various forms of life. An analogy founded on a single instance has no logical force. And it is doubtful whether we have not, in the moon, an instance which would as effectually serve to support a directly opposite conclusion. It seems all but certain, as we shall presently have occasion to show, that no part of the moon's globe is inhabited by living creatures. Certainly she is inhabited by none which bear the least resemblance to those existing on our earth. Thus it might fairly be urged that, since

one of the two orbs respecting which we know most appears to be uninhabited, there remains no probable argument in favour of the view that other orbs besides our earth are the abode of living creatures.

Yet the earth in reality supplies an argument of great force, when we consider the evidence she presents in another light. The mere fact that this world is inhabited is, as we have seen, little; but we shall find that the way in which life is distributed over the earth's surface is full of significance.

If we range over the earth, from the Arctic regions to the torrid zone, we find that none of the peculiarities which mark the several regions of our globe suffice to banish life from its surface. In the bitter cold within the Arctic Circles, with their strange alternations of long summer days and long winter nights, their frozen seas, perennial ice, and scanty vegetation, life flourishes in a hundred various forms. On the other hand, the torrid zone, with its blazing heat, its long-continued droughts, its strange absence of true seasonal changes, and its trying alternations of oppressive calms and fiercely raging hurricanes, nourishes even more numerous and more various forms of life than either of the great temperate zones. Around mountain summits as in the depth of the most secluded valleys, in mid-ocean as in the arid desert, in the air as beneath the surface of the earth, we find a myriad forms of life.

But this is far from being all. Various as are the physical habitudes which we encounter as we travel over the surface of our globe, we are able to trace the

existence of other varieties even more remarkable. The geologist has been able to turn back a few leaves of the earth's past history, and though the pages have been defaced and mutilated by Time's unsparing hand, he is yet able to read in them of many strange vicissitudes to which the continents and oceans of our globe have been exposed. But, far back as he can trace the earth's history—and already he counts her age by millions of years—he finds no evidence of an epoch when life was absent from her surface. Nay, if he reads aright the mysterious lesson which the blurred letters teach him, he is led to believe that, at the most distant epoch to which his researches have extended, there was the same wonderful variety in the forms of life as at the present day. He can, indeed, find the scattered remains of only a few of those old-world creatures; but he recognises in those which have been preserved the clearest evidence that thousands of others must have existed around them. He knows that of a million creatures now existing scarcely one will leave to future ages any record of its existence; he sees whole races vanishing from the earth, leaving no trace behind them; and he is thus able to form an estimate of the enormous extent by which the creatures and races of which he can learn *nothing* must have outnumbered those whose scattered remains attest their former existence upon the earth.

Here, then, we have analogies which there is no mistaking. We see that not only is Nature careful to fill all available space with living forms, but that no

time over which our researches extend has found her less prodigal of life. We see that, within very wide limits, she has a singular power of adapting living creatures to the circumstances which surround them. Nor is this lesson affected—like the general lesson drawn from the mere fact of the earth's being inhabited —by anything we can learn from the aspect of our satellite. For the arguments against the presence of living creatures on the moon are founded on the evidence we have that the physical habitudes of that orb are outside the limits within which Nature effects the adaptation spoken of.

The moon teaches us, however, that all the celestial bodies are not at all times habitable. The sun also teaches the same lesson. And it is necessary that we should consider how far the evidence presented by our own earth may serve to elucidate this teaching. We shall see that terrestrial analogies afford a very sure guide in the midst of many perplexities presented by the study of the worlds around us.

Let us trace out the various degrees of fitness or unfitness for the support of particular forms of life, which we recognise in various regions of our earth.

Often, where there exists so slight a difference between two regions of the earth that, to ordinary observation, it would appear that the forms of life existing in one should be well adapted to the other also, we yet find that this is not the case. Some minute peculiarity of soil, or climate, or vegetation, will render one region absolutely uninhabitable by a race which lives and

thrives in the other. Darwin mentions several instances in which an apparently insignificant change in the circumstances under which a particular race has thriven, and sometimes a change which does not, at first sight, appear to be in the least connected with the well-being of the race, has led to its gradual disappearance. And it seems demonstrated that even the slow processes of change to which every part of the earth is subjected would suffice to destroy a number of the races now subsisting on its surface, were the characteristics of those races unalterable. But as the physical habitudes of their abode slowly change, the various races of living creatures slowly change also, so as to adapt themselves continually to the varying circumstances under which they live.

The lesson taught us by this peculiarity is very obvious. On the one hand, we see that it would be by no means sufficient to indicate a general resemblance between the physical habitudes of our earth and those of some far distant planet, in order to prove that that planet is the abode of living creatures resembling those on our own earth. But, on the other hand, we are taught that the existence of differences sufficient to render a distant planet an unsuitable abode for such creatures as we are familiar with cannot force upon us the conclusion that the planet is uninhabited. On the contrary, the circumstance we have been considering teaches us that such differences as would suffice to banish life of certain kinds are insufficient to banish life of all kinds, or even to render less abundant the

forms of life which exist under those changed conditions.

And now we may proceed a step farther. On our earth we find differences of climate and of physical habitudes generally, which are much more important than those hitherto dealt with. We see that not only would certain races perish in the long run, if removed from their own abode to other parts of the earth, but that, in some instances, the process of destruction would be very rapid indeed. If we were to remove the polar bears from their Arctic fastnesses to tropical, or even to the warmer parts of temperate regions, a very few years would see the end of the whole race. The races inhabiting steppes and prairies would quickly perish if removed to mountain regions. Those accustomed to a moisture-laden air and abundant vegetation would not survive long if removed to the desert.

In some races, indeed, we find a power of enduring such changes which very far exceeds that possessed by other races. Those creatures, for example, which man has domesticated seem capable of enduring a variety of climate or of circumstances, which would destroy the seemingly more vigorous races not yet subdued to the yoke of man.[1]

[1] Humboldt tells us that 'the pliability of the organisation of those animals which man has subjected to his sway enables horses, cows, and other species of European origin to lead for a time an amphibious life, surrounded by crocodiles, water-serpents, and manatees. When the rivers return again to their beds, the horses roam in the savannah, which is then spread over with a fine odoriferous grass; and enjoy, as in their native climate, the renewed vegetation of spring.'

Even man himself, however, though he possesses in an unrivalled degree the power of enduring in safety the most complete change of climate, scene, and circumstances, is yet limited, in a certain sense, in his power of migration. The Englishman, for example, can endure the fiercest heat of the tropics or the bitterest cold of Arctic and Antarctic regions. But he cannot safely attempt to found true colonies in every part of the earth's surface. Our countrymen in India must send their children to be reared in England, if they wish them to grow up strong and vigorous. There can be little doubt that if a thousand men and women from this country were to settle in certain parts of India (not at any time intermarrying with the natives), the colony would disappear within a couple of centuries.

Here we have a second degree of unfitness, according to which certain countries would quickly become depopulated, if supplied with inhabitants from certain other countries. We are taught the same lesson as before, but in a more striking manner. We see that differences exist within the confines of our own earth which render particular countries absolutely uninhabitable by particular races, insomuch that, though the individual might survive, the race itself would quickly perish. And we see, on the other hand, that these countries are not uninhabited, or even less fully peopled with living creatures, than seemingly more fortunate abodes.

Now, if some impassable barrier prevented the

inhabitants of one country from visiting others, while yet it was possible to learn something of the conditions prevailing in other regions, how readily the conclusion might be reached that some at least of those inaccessible regions must be wholly uninhabited, simply because their physical habitudes appeared unsuited to the wants of the only creatures with which the observer was familiar. Who would believe, for example, that men can live, and not only live but thrive and multiply, in the frost-bound regions within the Arctic Circle, if travellers had not visited the Esquimaux races, and witnessed the conditions under which they subsist? Again, if we knew nothing of India, and some one pictured to us the intense heat of the Indian sun, the strange alternations of weather which replace to the Indian the seasonal changes we are familiar with, and all the other circumstances which render tropical regions so different from our English home, who could believe that, amidst those seemingly unendurable vicissitudes, there are races of men that thrive and multiply, even as our people in their temperate zone? [1]

Therefore, in examining the circumstances of other

[1] Perhaps the most striking instance of man's power of living under circumstances seemingly the most unfavourable is to be found in the fact that though the strongest traveller is affected seriously by the rarity of the air at great elevations, yet races of men live and thrive in Potosi, Bogotà, and Quito, and—to use the words of a modern writer—that bull-fights should be possible at an elevation at which Saussure hardly had energy to consult his instruments, and where even his guides fainted as they tried to dig a small hole in the snow

worlds than ours, it will not be sufficient to prove that certain orbs would obviously not be habitable by the races subsisting on the earth, in order to enforce the conclusion that no living creatures subsist at all upon their surface.

Yet another step farther, however. There are regions of the earth where the members of races belonging to other regions *quickly* perish. The air of our own England is death to many creatures. And indeed, there is not a spot in the whole world which would not be fatal in a brief space to many animals and plants belonging to other regions. Yet each spot, though thus fatal to certain races, is inhabited by numbers of others which live and thrive upon its surface.

Here, then, is our third lesson. We are taught by the analogy of our earth that it is not even sufficient to show that a planet would be an abode quickly fatal to all the living creatures subsisting on our globe to prove that it is therefore uninhabited.

But we have yet a stronger argument to touch on. There are regions of our earth to which creatures from other regions cannot be removed without being *immediately* killed. The warm-blooded animal perishes if placed for a brief space under water. The fish perishes if placed for a brief space on the earth.[1] What could be more wonderful to us, were we not familiar with

[1] Perhaps the fact that there are certain kinds of fish which can not only live out of water, but can travel across the dry land, or climb trees, affords an even more striking instance of Nature's power of adapting creatures to the circumstances which surround them

the fact, than that there are living creatures within the depths of that ocean beneath whose surface we ourselves, and the land creatures we are familiar with, cannot remain alive many minutes? If fishes could reason, how could they believe that creatures can live in comfort in that element which is death to them? Yet land and river and sea are alike peopled with living creatures, each race as well adapted as its fellows to the circumstances in which it is placed.

We are taught, then, yet another lesson. We see that even though we could prove that every living creature on this earth would at once perish if removed to another orb, yet we cannot thence conclude that that orb is uninhabited. On the contrary, the lesson conveyed by our earth's analogy leads to the conclusion that many worlds may exist, abundantly supplied with living creatures of many different species, where yet every form of life upon our earth—bird, beast, or fish, reptile, insect, or animalcule—would perish in a few moments.[1]

There remains yet a last lesson to be drawn from terrestrial analogies. On the earth there are regions

[1] I might add to the instances here cited many others which seem even more striking. We know that in strong acids which would instantly kill bird, beast, fish, or insect placed within them, there exist and thrive minute creatures, adapted by Nature to the strange conditions in which they are placed. Even in the bowels of the earth and in the very neighbourhood of active volcanoes, we find the Volcano-fish existing in such countless thousands that when they are from time to time vomited forth by the erupting mountain their bodies are strewn over enormous regions, and, as they putrefy beneath the sun's rays, spread pestilence and disease among the inhabitants of the neighbouring districts.

where no form of life exists or can exist. Within the flaming crater of the volcano, or in the frozen heart of the iceberg, no living creature has its being. Yet even here Nature proves to us that the great end and aim of all her working is to afford scope and room for new forms of life, or to supply the wants of those which already exist. The volcano will die out, and the scene of its activity will one day become the abode of myriads of living creatures who would have perished in a moment in its consuming fires. The iceberg will melt, and its substance will once again be peopled with busy life. But this is little. It is the work of which volcano and iceberg are the signs, which most significantly teaches us what is Nature's real aim. The volcano is the index of those busy subterranean forces which are remodelling the earth's frame, slowly changing the level of the land, making continents of oceans and oceans of continents, preserving and vivifying all things, while all things seem to suffer a gradual destruction. The iceberg, too, has its work in remodelling and fashioning the surface of new continents. It also acts an important part in the formation and maintenance of the system of oceanic circulation on which the welfare of land creatures and water creatures so largely depends. And so of a multitude of other phenomena, which appear at first sight significant rather of the destructive than of the life-preserving character of Nature. The tornado and the thunder-storm, the earthquake and the volcano—nay, even the dreaded returns of plague and pestilence, have each a more

powerful influence by far towards the preservation than they have towards the destruction of life.

We see, then, that even if we could prove that an orb in space is so circumstanced that no life could by any possibility exist upon its surface; if it were the scene of a fierce and destructive turmoil, one moment of which would suffice to destroy every living creature now existing upon the earth; if its whole mass were heated to a degree a thousandfold more intense than that of the fiercest heat we know of; if its surface were bound in a cold compared with which our Arctic frosts would seem like tropical heat; or even if the most rapid alternation of these extremes took place upon and within it—even then we could not conclude that it has not been in long-past ages, or will not be in ages yet to come, the abode of life.

Lastly, even when we can safely assert of any celestial object that neither now, nor at any past or future time, could it serve as the abode of living creatures, we are led by terrestrial analogies to the conclusion that it yet supports life in other ways. So that these very orbs, of which it seems safest to assert that they are, have ever been, and must ever remain uninhabited, speak to us, no less strongly than those which appear best suited for habitation, of the existence of other worlds than ours.

CHAPTER II.

WHAT WE LEARN FROM THE SUN.

I do not propose to dwell in this chapter on the views which have been propounded respecting the sun's habitability. It is not merely that I regard those views as too fanciful to find place in a serious consideration of the subject I am dealing with, nor that the progress of recent observation has rendered them utterly untenable, but that, in fact, they do not belong to what the sun teaches us. I wish to consider only the real evidence which the sun affords respecting the scheme of creation, to dwell upon the purposes which he subserves in the economy of the solar system, and thence to deduce a lesson respecting those other suns scattered through space which we call the fixed stars.

Let us first endeavour to form adequate conceptions respecting the dimensions of the great central luminary of the solar system.

Let the reader consider a terrestrial globe three inches in diameter, and search out on that globe the tiny triangular speck which represents Great Britain. Then let him endeavour to picture the town in which

he lives as represented by the minutest pin-mark that could possibly be made upon this speck. He will then have formed some conception, though but an inadequate one, of the enormous dimensions of the earth's globe, compared with the scene in which his daily life is cast. Now, on the same scale, the sun would be represented by a globe about twice the height of an ordinary sitting-room. A room about twenty-six feet in length, and height, and breadth, would be required to contain the representation of the sun's globe on this scale, while the globe representing the earth could be placed in a moderately large goblet.

Such is the body which sways the motions of the solar system. The largest of his family, the giant Jupiter, though of dimensions which dwarf those of the earth or Venus almost to nothingness, would yet only be represented by a thirty-two inch globe, on the scale which gives to the sun the enormous volume I have spoken of. Saturn would have a diameter of about twenty-eight inches, his ring measuring about five feet in its extreme span. Uranus and Neptune would be little more than a foot in diameter, and all the minor planets would be less than the three inch earth. It will thus be seen that the sun is a worthy centre of the great scheme he sways, even when we merely regard his dimensions.

The sun outweighs fully 730 times the combined mass of all the planets which circle around him, so that when we regard the energy of his attraction, we still find him a worthy ruler of the planetary scheme.

But, after all, the enormous volume and mass of the sun form the least important of his characteristics as the ruling body of the solar system. It is when we contemplate him as the source whence the supplies of heat and light required by our own world and the other planets are plentifully bestowed that we see what is his chief office in the economy of the planetary scheme.

Properly speaking, the physical constitution of the sun only requires to be dealt with in such a work as the present, in so far as it is directly associated with the sun's action upon the worlds around him, or as it may bear on the question of the constitution of those worlds. But the subject is so interesting, and it would indeed be so difficult to draw a line of demarcation between the facts which bear upon the question of other worlds and those which do not, that I may be permitted to enter at some length into a consideration of the solar orb, as modern physical discoveries present it to our contemplation.

The study of solar physics may be said to have commenced with the discovery of the sun-spots, about 267 years ago. These spots were presently found to traverse the solar disc in such a way as to indicate that the sun turns upon an axis once in about twenty-six days. Nor will this rotation appear slow when we remember that it implies a motion of the equatorial parts of the sun's surface at a rate exceeding some seventy times the motion of our swiftest express trains.

Next came the discovery that the solar spots are not surface stains, but deep cavities in the solar substance. The changes of appearance presented by the spots as they traverse the solar disc, led Dr. Wilson to form this theory so far back as 1779; but, strangely enough, it is only in comparatively recent times that the hypothesis has been finally established. For even within the last ten years a theory was put forward which accounted satisfactorily for most of the changes of appearance observed in the spots, by supposing them to be due to solar clouds hanging suspended at a considerable elevation above the true photosphere.

Sir William Herschel, reasoning from terrestrial analogies, was led to look on the spot cavities as apertures through a double layer of clouds. He argued that were the solar photosphere of any other nature, it would be past comprehension that vast openings should form in it, to remain open for months before they close up again. Whether we consider the enormous rapidity with which the spots form and with which their figure changes, or the length of time that many of them remain visible, we find ourselves alike perplexed, unless we assume that the solar photosphere resembles a bed of clouds. Through a stratum of terrestrial clouds openings may be formed by atmospheric disturbances, but while undisturbed the clouds will retain any form once impressed upon them for a length of time corresponding to the weeks and months during which the solar spots endure.

And because the solar spots present two distinct

varieties of light, the faint penumbra and the dark umbra or nucleus, Herschel saw the necessity of assuming that there are two beds of clouds, the outer self-luminous and constituting the true solar photosphere, the inner reflecting the light received from the outer layer, and so shielding the real surface of the sun from the intense light and heat which it would otherwise receive.

But while recent discoveries have confirmed Sir William Herschel's theory about the solar cloud-envelopes, they have by no means given countenance to his view that the body of the sun may possibly be cool. The darkness of the nucleus of a spot is found, on the contrary, to give proof that in that neighbourhood the sun is hotter, because it parts less readily with its heat. We shall see presently how this is. Meantime let it be noticed in passing that a close scrutiny of large solar spots has revealed the existence of an intensely dark spot in the midst of the umbra. This spot must be regarded as the true nucleus.

The circumstance that the spots appear only on two bands of the sun's globe, corresponding to the sub-tropical zones on our own earth, led the younger Herschel to conclusions as important as those which his father had formed. He reasoned, like his father, from terrestrial analogies. On our own earth the sub-tropical zones are the regions where the great cyclonic storms have their birth, and rage with their chief fury. Here, therefore, we have the analogue of the solar spots, if only we can show reason for believing that

any causes resembling those which generate the terrestrial cyclone operate upon those regions of the sun where the solar spots make their appearance.

We know that the cyclone is due to the excess of heat at the earth's equator. It is true that this excess of heat is always in operation, whereas cyclones are not perpetually raging in sub-tropical climates. Ordinarily, therefore, the excess of heat does not cause tornadoes. Certain aërial currents are generated, whose uniform motion suffices, as a rule, to adjust the conditions which the excess of heat at the equator would otherwise tend to disturb. But when through any cause the uniform action of the aërial currents is either interfered with, or is insufficient to maintain equilibrium, then cyclonic or whirling motions are generated in the disturbed atmosphere, and propagated over a wide area of the earth's surface.

Now we recognise the reason of the excess of heat at the earth's equator, in the fact that the sun shines more directly upon that part of the earth than on the zones which lie in higher latitudes. Can we find any reason for suspecting that the sun, which is not heated from without as the earth is, should exhibit a similar peculiarity? Sir John Herschel considered that we can. If the sun has an atmosphere extending to a considerable distance from his surface, then there can be little doubt that, owing to his rotation upon his axis, this atmosphere would assume the figure of an oblate spheroid, and would be deepest over the solar equator. Here, then, more of the sun's heat

would be retained than at the poles, where the atmosphere is shallowest. Thus that excess of heat at the solar equator which is necessary to complete the analogy between the sun-spots and terrestrial cyclones seems satisfactorily established.

It must be remarked, however, that this reasoning, so far as the excess of heat at the sun's equator is concerned, only removes the difficulty a step. If there were indeed an increased depth of atmosphere over the sun's equator sufficient to retain the requisite excess of heat, then the amount of heat we receive from the sun's equatorial regions ought to be appreciably less than the amount emitted from the remaining portions of the solar surface. This is not found to be the case, so that, either there is no such excess of absorption, or else the solar equator gives out more heat, in other words, is essentially hotter, than the rest of the sun. But this is just the peculiarity of which we want the interpretation.

It may be taken for granted, however, that there is an analogy between the sun-spots and terrestrial cyclonic storms, though as yet we are not very well able to understand its nature.

We come next to one of the most interesting discoveries ever made respecting the sun—the discovery that the spots increase and diminish in frequency in a periodic manner. We owe this discovery to the laborious and systematic observations made by Herr Schwabe, of Dessau. In these pages any account of his work would be out of place. We need only dwell

upon the result, and upon other discoveries which have been made by observers who have taken up the same work.

Schwabe found that in the course of about eleven years the solar spots pass through a complete cycle of changes. They become gradually more and more numerous up to a certain maximum, and then as gradually diminish. At length the sun's face becomes not only clear of spots, but a certain well-marked darkening around the border of his disc disappears altogether for a brief season. At this time the sun presents a perfectly uniform disc. Then gradually the spots return, become more and more numerous, and so the cycle of changes is run through again.

The astronomers who have watched the sun from the Kew observatory have found that the process of change by which the spots sweep in a sort of 'wave of increase' over the solar disc is marked by several minor variations. As the surface of a great sea-wave will be traversed by small ripples, so the gradual increase and diminution in the number of the solar spots is characterised by minor gradations of change, which are sufficiently well marked to be distinctly cognisable.

There seems every reason for believing that the periodic changes thus noticed are due to the influence of the planets upon the solar photosphere, though in what way that influence is exerted is not at present perfectly clear. Some have thought that the mere attraction of the planets tends to produce tides of some sort in the solar envelopes. Then, since the

height of a tide so produced varies as the cube or third power of the distance, it has been thought that a planet when in perihelion would generate a much larger solar tide than when in aphelion. So that, as Jupiter has a period nearly equal to the sun-spot period, it has been supposed that the attractions of this planet are sufficient to account for the great spot-period. Venus, Mercury, the Earth, and Saturn have, in a similar manner, been rendered accountable for the shorter and less distinctly marked periods.

Without denying that the planets may be, and probably are, the bodies to whose influence the solar-spot periods are to be ascribed, I yet venture to express very strong doubts whether the action of Jupiter is so much greater in perihelion than in aphelion as to account for the fact that, whereas at one season the face of the sun shows many spots, at another it is wholly free from them.

However, we are not at present concerned so much with the explanation of facts as with the facts themselves. We have to consider rather what the sun is, and what he does for the solar system, than why these things are so.

Let us note, before passing to other circumstances of interest connected with the sun, that the variable condition of his photosphere must cause him to change in brilliancy as seen from vast distances. If Herr Schwabe, for instance, instead of observing the sun's spots from his watch tower at Dessau, could have removed himself to a distance so enormous that the sun's

disc would have been reduced, even in the most powerful telescope, to a mere point of light, there can be no doubt that the only effect which he would have been able to perceive would have been a gradual increase and diminution of brightness, having a period of about eleven years.

Our sun, therefore, if viewed from the neighbourhood of any of the stars, whence undoubtedly he would simply appear as one among many fixed stars, would be a 'variable,' having a period of about eleven years, and a very limited range of variation. Further, if an observer, viewing the sun from so enormous a distance, had the means of very accurately measuring its light, he would undoubtedly discover that while the chief variation of the sun takes place in a period of about eleven years, its light is subjected to minor variations, having shorter periods.

The discovery that the periodic changes of the sun's appearance are associated with the periodic changes in the character of the earth's magnetism is the next that we have to consider.

It had long been noticed that during the course of a single day the magnetic needle exhibits a minute change of direction, taking place in an oscillatory manner. And when the character of this vibration came to be carefully examined, it was found to correspond to a sort of effort on the needle's part to turn towards the sun. For example, when the sun is on the magnetic meridian, the needle has its mean position. This happens twice in the day, once when the

sun is above the horizon, and once when he is below it. Again, when the sun is midway between these two positions—which also happens twice in the day—the needle has its mean position, because the northern and the southern ends make equal efforts, so to speak, to direct themselves towards the sun. Four times in the day, then, the needle has its mean position, or is directed towards the magnetic meridian. But when the sun is not in one of the four positions considered, that end of the needle which is nearest to him is slightly turned away from its mean position, towards him. The change of position is very minute, and only the exact methods of observation made use of in the present age would have sufficed to reveal it. There it is, however, and this minute and seemingly unimportant peculiarity has been found to be full of meaning.

Had science merely measured this minute variation, the work would have given striking evidence of the exact spirit in which men of our day deal with natural phenomena. But science was to do much more. The variations of this minute variation were to be inquired into; their period was to be searched for; the laws by which they were regulated, and by which their period might perhaps itself be rendered variable, were to be examined; and finally their relation to other natural laws was to be sought after. That science should set herself to an inquiry so delicate and so difficult, in a spirit so exacting, was nothing unusual. It is thus that all the great discoveries of our age have been effected. But it is well that the reader should recognise the

careful scrutiny to which natural phenomena have been subjected before the great laws we have to consider were made known. It is thought by many, who have not been at the pains to examine what science is really doing in our day, that the wonders she presents to men's contemplation, the startling revelations which are being made from day to day, are merely dreams and fancies, which replace indeed the dreams and fancies of old times, but have no worthier claims on our belief. Those who carefully examine the history of science will be forced to adopt a very different opinion.

The minute vibrations of the magnetic needle, thus carefully watched—day after day, month after month, year after year—were found to exhibit a yet more minute oscillatory change. They waxed and waned within narrow limits of variation, but yet in a manner there was no mistaking. The period of this oscillatory change was not to be determined, however, by the observations of a few years.[1] Between the time when the diurnal vibration was least until it had reached its greatest extent, and thence returned to its first value, no less than eleven years elapsed, and a much longer time passed before the periodic character of the change was satisfactorily determined.

[1] The reader must not understand that the account here given presents in any sense even a general view of the labours of those who have studied the earth's magnetism. I touch only on those points by which the association between the earth's magnetism and the physical condition of the sun are most clearly indicated; because these points alone bear on the subject of this chapter. How they do so will appear further on.

The reader will at once see what these observations tend to. The sun-spots vary in frequency within a period of eleven years, and the magnetic diurnal observations vary within a period of the same duration. It might seem fanciful to associate the two periodic series of changes together, and doubtless when the idea first occurred to Sabine, it was not with any great expectation of finding it confirmed, that he examined the evidence bearing on the point. Judging from known facts, we may see reasons for such an expectation in the correspondence of the needle's diurnal vibration, with the sun's apparent motion, and also in the law which associates the annual variations of the magnet's power with the sun's distance. But undoubtedly when the idea occurred to Sabine, it was an exceedingly bold one, and the ridicule with which the first announcement of the supposed law was received, even in scientific circles, suffices to show how unexpected that relation was which is now so thoroughly established. For a careful comparison between the two periods has demonstrated that they agree most perfectly, not merely in length, but maximum for maximum, and minimum for minimum. When the sun-spots are most numerous, then the daily vibration of the magnet is most extensive; while when the sun's face is clear of spots, the needle vibrates over its smallest diurnal arc.

Then the intensity of the magnetic action has been found to depend upon solar influences. The vibrations by which the needle indicates the progress of

those strange disturbances of the terrestrial magnetism which are known as magnetic storms, have been found not merely to be most frequent when the sun's face is most spotted, but to occur simultaneously with the appearance of signs of disturbance in the solar photosphere. For instance, during the autumn of 1859 the eminent solar observer, Carrington, noticed the apparition of a bright spot upon the sun's surface. The light of this spot was so intense that he imagined the screen which shaded the plate employed to receive the solar image had been broken. By a fortunate coincidence another observer, Mr. Hodgson, happened to be watching the sun at the same instant, and witnessed the same remarkable appearance. Now it was found that the self-registering magnetic instruments of the Kew observatory had been sharply disturbed at the instant when the bright spot was seen. And afterwards it was learned that the phenomena which indicate the progress of a magnetic storm had been observed in many places. Telegraphic communication was interrupted, and at a station in Norway the telegraphic apparatus was set on fire; auroras appeared both in the northern and southern hemispheres during the night which followed; and the whole frame of the earth seemed to thrill responsively to the disturbance which had affected the great central luminary of the solar system.

The reader will now see why I have discussed relations which hitherto he may perhaps have thought very little connected with my subject. He sees that

there is a bond of sympathy between our earth and the sun; that no disturbance can affect the solar photosphere without affecting our earth to a greater or less degree. But if our earth, then also the other planets. Mercury and Venus, so much nearer the sun than we are, surely respond even more swiftly and more distinctly to the solar magnetic influences. But beyond our earth, and beyond the orbit of moonless Mars, the magnetic impulses speed with the velocity of light. The vast globe of Jupiter is thrilled from pole to pole as the magnetic wave rolls in upon it; then Saturn feels the shock, and then the vast distances beyond which lie Uranus and Neptune are swept by the ever-lessening yet ever-widening disturbance-wave. Who shall say what outer planets it then seeks? or who, looking back upon the course over which it has travelled, shall say that planets alone have felt its effects? Meteoric and cometic systems have been visited by the great magnetic wave, and upon the dispersed members of the one and the subtle structure of the other effects even more important may have been produced than those striking phenomena which characterise the progress of terrestrial or planetary magnetic storms.

When we remember that what is true of a relatively great solar disturbance, such as the one witnessed by Messrs. Carrington and Hodgson, is true also (however different in degree) of the magnetic influences which the sun is at every instant exerting, we see that a new and most important bond of union exists between the members of the solar family. The sun

not only sways them by the vast attraction of his gravity, not only illumines them, not only warms them, but he pours forth on all his subtle yet powerful magnetic influences. A new analogy between the members of the solar system is thus introduced.

And now we pass on to other discoveries, bearing at once and with equal force upon the relations between the various members of the solar system and upon the position which that system occupies in the universe.

Hitherto we have been considering the teachings of the telescope; we have now to consider what we have learned by means of an instrument of yet higher powers. As I shall have to refer very frequently, throughout this volume, to the teachings of the spectroscope, it will be well that I should briefly describe what it is that this instrument really effects. Were I simply to state the results of its use, without describing its real character, many of my readers would be disposed to believe that astronomers are as credulous as in reality they are exacting and scrupulous, where new facts and observations are in question.

The real end and aim of the telescope, as applied by the astronomer to the examination of the celestial objects, is to gather together the light which streams from each luminous point throughout space. We may regard the space which surrounds us on every side as an ocean without bounds or limits, an ocean across which there are ever sweeping waves of light either emitted directly from the various bodies subsisting

throughout space, or else reflected from their surfaces. Other forms of wave also speed across those limitless depths in all directions; but the light-waves are those which at present concern us. Our earth is as a minute island placed within the ocean of space, and to the shores of this tiny isle the light-waves bear their message from the orbs which lie like other isles amid the fathomless depths around us. With the telescope the astronomer gathers together portions of light-waves which else would have travelled in diverging directions. By thus intensifying their action, he enables the eye to become cognisant of their true nature. Precisely as the narrow channels around our shores cause the tidal wave, which sweeps across the open ocean in almost insensible undulations, to rise and fall through a wide range of variation, so the telescope renders sensible the existence of light-waves which would escape the notice of the unaided eye.

The telescope, then, is essentially a *light-gatherer*.

The spectroscope is used for another purpose. It might be called the *light-sifter*. It is applied by the astronomer to analyse the light which comes to him from beyond the ocean of space, and so to enable him to learn the character of the orbs from which that light proceeds.

The principle of the instrument is simple, though the appliances by which its full powers can alone be educed are somewhat complicated.

A ray of sunlight falling on a prism of glass or crystal does not emerge unchanged in character.

Different portions of the ray are differently bent, so that when they emerge from the prism they no longer travel side by side as before. The violet part of the light is bent most, the red least; the various colours from violet through blue, green, and yellow, to red, being bent gradually less and less.

The prism then *sorts*, or *sifts*, the light-waves.

But we want the means of sifting the light-waves more thoroughly. The reader must bear with me while I describe, as exactly as possible in the brief space available to me, the way in which the first rough work of the prism has been modified into the delicate and significant work of the spectroscope. It is well worth while to form clear views on this point, because so many of the wonders of modern science are associated with spectroscopic analysis.

If, through a small round hole in a shutter, light is admitted into a darkened room, and a prism be placed with its refracting angle downwards and horizontal, a vertical spectrum, having its violet end uppermost, will be formed on a screen suitably placed to receive it.

But now let us consider what this spectrum really is. If we take the light-waves corresponding to any particular colour, we know from optical considerations that these waves emerge from the prism in a pencil exactly resembling in shape the pencil of white light which falls on the prism. They therefore form a small circular or oval image on their own proper part of the spectrum. Hence the spectrum is in reality formed of

a multitude of overlapping images, varying in colour from violet to red. It thus appears as a rainbow-tinted streak, presenting every gradation of colour between the utmost limits of visibility at the violet and red extremities.

If we had a square aperture to admit the light, we should get a similar result. If the aperture were oblong, there would still be overlapping images; but if the length of the oblong were horizontal, then, since each image would also be a horizontally-placed oblong, the overlapping would be less than when the images were square. Suppose we diminish the overlapping as much as possible; in other words, suppose we make the oblong slit as narrow as possible. Then, unless there were in reality an infinite number of images distributed all along the spectrum from top to bottom, the images might be so narrowed as not to overlap; in which case, of course, there would be horizontal dark spaces or gaps in our spectrum. Or again, if we failed in finding gaps of this sort by simply narrowing the aperture, we might lengthen the spectrum by increasing the refracting angle of the prism, or by using several prisms, and so on.

The first great discovery in solar physics, by means of the analysis of the prism (though the discovery had little meaning at the time), consisted in the recognition of the fact that by means of such devices as the above, dark gaps or cross-lines *can* be seen in the solar spectrum. In other words, light-waves of the various gradations corresponding to all the tints of the spec-

trum from violet to red, do *not* travel to us from the great central luminary of our system. Remembering that the effect we call colour is due to the length of the light-waves, the effect of red corresponding to light-waves of the greatest length, while the effect of violet corresponds to the shortest light-waves, we see that in effect the sun sends forth to the worlds which circle around him light-waves of many different lengths, but not of all lengths. Of so complex and interesting a nature is ordinary daylight.

But spectroscopists sought to interpret these dark lines in the solar spectrum, and it was in carrying out this inquiry—which even to themselves seemed almost hopeless, and to many would appear an utter waste of time—that they lighted upon the noblest method of research yet revealed to man.

They examined the spectra of the light from incandescent substances (white-hot metals and the like), and found that in these spectra there are no dark lines.

They examined the spectra of the light from the stars, and found that these spectra are crossed by dark lines resembling those in the solar spectrum, but differently arranged.

They tried the spectra of glowing vapours, and they obtained a perplexing result. Instead of a number of dark lines across a rainbow-tinted streak, they found bright lines of various colour. Some gases would give a few such lines, others many, some only one or two.

Then they tried the spectrum of the electric spark, and they found here also a series of bright lines, but

not always the same series. The spectrum varied according to the substances between which the spark was taken and the medium through which it passed.

Lastly, they found that the light from an incandescent solid or liquid, when shining through various vapours, no longer gives a spectrum without dark lines, but that the dark lines which then appear vary in position, according to the nature of the vapour through which the light has passed.

Here were a number of strange facts, seemingly too discordant and too perplexing to admit of being interpreted. Yet one discovery only was wanting to bring them all into unison.

In 1859 Kirchhoff, while engaged in observing the solar spectrum, lighted on the discovery that a certain double dark line, which had already been found to correspond exactly in position with the double bright line forming the spectrum of the glowing vapour of sodium, was intensified when the light of the sun was allowed to pass through that vapour. This at once suggested the idea that the presence of this dark line (or, rather, pair of dark lines) in the spectrum of the sun is due to the existence of the vapour of sodium in the solar atmosphere, and that this vapour has the power of absorbing the same order of light-waves as it emits. It would of course follow from this that the other dark lines in the solar spectrum are due to the presence of other absorbent vapours in its atmosphere, and that the identity of these would admit of being established in the same way, supposing this general law to hold

that a vapour emits the same light-waves that it is capable of absorbing.

Kirchhoff was soon able to confirm his views by a variety of experiments. The general principles to which his researches led—in other words, the principles which form the basis of spectrum analysis—are as follow:

1. An incandescent solid or liquid gives a continuous spectrum.

2. A glowing vapour gives a spectrum of bright lines, each vapour having its own set of lines, so that from the appearance of a bright-line spectrum one can tell the nature of the vapour or vapours whose light forms the spectrum.

3. An incandescent solid or liquid shining through absorbent vapours gives a rainbow-tinted spectrum crossed by dark lines, these dark lines having the same position as the bright lines belonging to the spectra of the vapours; so that, from the arrangement of the dark lines in such a spectrum, one can tell the nature of the vapour or vapours which surround the source of light.[1]

[1] To these may be added the following laws:

4. Light reflected from any opaque body gives the same spectrum as it would have given before reflection.

5. But if the opaque body be surrounded by vapours, the dark lines corresponding to these vapours make their appearance in the spectrum with a distinctness proportioned to the extent to which the light has penetrated those vapours before being reflected to us.

6. If the reflecting body be itself luminous, the spectrum belonging to it is superadded to the spectrum belonging to the reflected light.

7. Glowing vapours surrounding an incandescent source of light

The application of the new method of research to the study of the solar spectrum quickly led to a number of most interesting discoveries. It was found that besides sodium the sun's atmosphere contains the vapours of iron, calcium, magnesium, chromium, and other metals. The dark lines corresponding to these elements appear unmistakably in the solar spectrum. There are other metals—such as copper and zinc—which seem to exist in the sun, though some of the corresponding dark lines have not yet been recognised. As yet it has not been proved that gold, silver, mercury, tin, lead, arsenic, antimony, or aluminium exist in the sun—though we can by no means conclude, nor indeed is it at all probable, that they are absent from his substance. The dark lines belonging to hydrogen are very well marked indeed in the solar spectrum, and, as we shall see presently, the study of these lines has afforded most interesting information respecting the physical constitution of the sun.

Now, we notice at once how importantly these researches into the sun's structure bear upon the sub-

may cause bright lines or dark lines to appear in the spectrum, according as they are more or less heated; or they may emit just so much light as to make up for what they absorb, in which case there will remain no trace of their presence.

8. The electric spark presents a bright-line spectrum, compounded of the spectra belonging to the vapours of those substances between which, and of those through which, the discharge takes place. According to the nature of these vapours and of the discharge itself, the relative intensity of the component parts of the spectrum will be variable.

Lastly, the appearance of the spectrum belonging to any element will vary according to the circumstances of pressure and temperature under which the element may emit light.

ject of this treatise. It would be indeed interesting to consider the actual condition of the central orb of the planetary scheme, to picture in imagination the metallic oceans which exist upon his surface, the continual evaporation from those oceans, the formation of metallic clouds, and the downpour of metallic showers upon the surface of the sun. But apart from such considerations, and viewing Kirchhoff's discoveries simply in their relation to the subject of other worlds, we have enough to occupy our attention.

If it could have been shown that, in all probability, the substance of the sun consists of materials wholly different from those which exist in this earth, the conclusion obviously to be drawn from such a discovery would be that the other planets also are differently constituted. We could not find any just reason for believing that in Jupiter or Mars there exist the elements with which we are acquainted, when we found that even the central orb of the planetary system exhibits no such feature of resemblance to the earth. But now that we know quite certainly that the familiar elements iron, sodium, and calcium exist in the sun's substance, while we are led to believe, with almost perfect assurance, that all the elements we are acquainted with also exist there, we see at once that in all probability the other planets are constituted in the same way. There may of course be special differences. In one planet the proportionate distribution of the elements may differ, and even differ very markedly from that which prevails in some other planet,

But the general conclusion remains, that the planets are formed of the elements which have so long been known as terrestrial; for we cannot recognise any reason for believing that our earth alone, of all the orbs which circle around the sun, resembles that great central orb in general constitution.[1]

Now, we have in this general law a means of passing beyond the bounds of the solar system, and forming no indistinct conceptions as to the existence and character of worlds circling around other suns. For it will be seen in the chapter on the stars that these orbs, like our sun, contain in their substance many of the so-called terrestrial elements, while it may not unsafely be asserted that all or nearly all those elements, and few or no elements unknown to us, exist in the substance of every single star that shines upon us from the celestial concave. Hence we conclude that around those suns also there circle orbs constituted like themselves, and therefore containing the elements with which we are familiar. And the mind is immediately led to speculate on the uses which those elements are intended to subserve. If iron, for example, is present in some noble orb circling around Sirius, we speculate not unreasonably respecting the existence on that orb —either now, or in the past, or at some future time— of being capable of applying that metal to the useful purposes which man makes it subserve. The imagi-

[1] It will be seen, in the chapter on 'Meteors and Comets,' that this conclusion has a most important bearing on the views we are to form respecting the original formation of the planetary scheme.

nation suggests immediately the existence of arts and sciences, trades and manufactures, on that distant world. We know how intimately the use of iron has been associated with the progress of human civilisation, and though we must ever remain in ignorance of the actual condition of intelligent beings in other worlds, we are yet led, by the mere presence of an element which is so closely related to the wants of man, to believe, with a new confidence, that for such beings those worlds must in truth have been fashioned.

I would fain dwell longer on the thoughts suggested by the researches of Kirchhoff. Gladly, too, would I enter at length on an account of those interesting discoveries which have been made in connection with recent total eclipses of the sun. The requirements of space, however, and some doubt as to the direct bearing of the last-named discoveries on the subject I have in hand, warn me to forbear. One point, however, remains, which is too intimately connected with my subject to be passed over.

I refer to the sun's corona.

It has been proved that the solar prominences consist of glowing vapours, hydrogen being their chief constituent. It has been found also, by comparing observations of the prominence-spectra with elaborate researches into the peculiarities presented by the spectrum of hydrogen at different pressures, that even in the very neighbourhood of the solar photosphere these vapours probably exist at a pressure so moderate as to

indicate that the limits of the sun's vaporous envelope cannot lie very far (relatively) from the outer solar cloud-layer.

Now the solar corona has been seen, during total eclipses of the sun, to extend to a distance at least equal to the sun's diameter from the eclipsed orb. So that, assuming the corona to be a solar atmosphere, it would have a depth of about 850,000 miles, and being also drawn towards the sun by his enormous attractive energy (exceeding more than twenty-seven times that of the earth), it could not fail to exert a pressure on his surface exceeding many thousand-fold that of our air upon the earth. In fact, such an atmosphere, let its outermost layers be as rare as we can conceive, would yet have its lower layers absolutely liquefied, if not solidified, by the enormous pressure to which they would be subjected. We cannot, then, believe this corona to be a solar atmosphere.

Yet it is quite impossible to dissociate the corona from the sun. Until 1872 some attempted to do this, and not only so, but to make of the zodiacal light a terrestrial phenomenon. But they had overlooked considerations which oppose themselves irresistibly to such a conclusion; and since the observation of the solar eclipse of December 1871, astronomers are of one accord in regarding the corona as appertaining to the sun.

But the spectroscope has given certain very perplexing evidence respecting the light of the corona, and it remains that we should endeavour to see how

that evidence bears on the interesting problem which the corona presents to our consideration.

During the total eclipse of August 1869 the American observers found that the spectrum of the corona is continuous, but crossed by certain bright lines. If we accept the absence of dark lines as established by the evidence (which is doubtful), this result seems at first sight very difficult to explain. Referring to the principles of spectroscopic analysis stated at pp. 38, 39, it will be seen that we should be led to infer that the corona consists of incandescent matter surrounded by certain glowing gases. It is difficult to suppose that this is the real explanation of the phenomenon.

Now, remembering that we have two established facts for our guidance—(i) the fact that the outer corona cannot be a solar atmosphere, and (ii) the fact that it must be a solar appendage—I think a way may be found towards a satisfactory explanation.

Let it be premised that the bright lines of the coronal spectrum correspond in position, though not in brightness, to those seen in the spectrum of the aurora, and that the same lines are seen in the spectrum of the zodiacal light, and in that of the phosphorescent light occasionally seen over the heavens at night.

Since we have every reason to believe that the light of the aurora is due to electrical discharges taking place in the upper regions of the air, we are invited to the belief that the coronal light may be due to similar discharges taking place between the particles (of whatever nature) constituting the corona.

Now, though the appearance of an aurora is due to some special terrestrial action (however excited), yet the material substances between which the discharges take place must be assumed to be at all times present in the upper regions of air. In all probability, they are the particles of those meteors which the earth is continually encountering. And since we know that meteor systems must be aggregated in far greater numbers near the sun than near the earth, we may regard the coronal light as due to electrical discharges excited by the sun's action, and taking place between the members of such systems. Besides this light, however, there must necessarily be a large proportion of light reflected from these meteoric bodies. In this way the peculiar character of the coronal spectrum may be readily accounted for. We know from the auroral spectrum that the principal bright lines due to the electrical discharges would be precisely where we see bright lines in the coronal spectrum. But, besides these, there would be fainter bright lines, corresponding to the various elements which exist in the meteoric masses. These elements, we know, are the same as those in the substance of the sun. Thus, the bright lines would correspond in position with the dark lines of the solar spectrum. Hence, as light reflected by the meteors would give the ordinary solar spectrum, there would result from the combination a continuous spectrum, on which the bright lines first mentioned would be seen, as during the American eclipse.

What the polariscope has told us respecting the corona is in accordance with this view.

In the same way the quality of the zodiacal light admits of being perfectly accounted for, without resorting to the hypothesis that this phenomenon is a terrestrial one.

The explanation thus put forward has at least the advantage of being founded on well-established relations. We know that the auroral light is associated with the earth's magnetism, and that meteoric bodies are continually falling upon the earth's atmosphere. We know also that the sun exerts magnetic influences a thousand-fold more intense than those of the earth, and that in his neighbourhood there must be many million times more meteoric systems.

But we have other and independent reasons, which must not be overlooked, for considering the corona to be of some such nature as I have suggested.

Leverrier has shown that there probably exists in the neighbourhood of the sun a family of bodies whose united mass suffices appreciably to affect the motions of the planet Mercury. It would not be safe to neglect considerations thus vouched for.

Now, whatever opinion we form as to the exact character of the system of bodies pointed to by Leverrier's researches — whether we suppose that system to form a zone around the sun, or that (as I believe) the system is merely due to the aggregation of meteoric perihelia in the sun's neighbourhood—we

may be quite certain that during a total solar eclipse the system would become visible.

In the eclipse of December 1871 striking evidence was obtained respecting the corona. For Janssen was able to perceive the solar dark lines in the spectrum of the corona—proof unmistakable that a portion of the coronal light is reflected sunlight. It had been a difficulty in the meteoric theory that these solar lines had not been detected in the faint continuous spectrum of the corona. The meteoric theory, that is, the theory that a portion of the coronal light is due to light-reflecting meteors round the sun, accorded with all the known phenomena of the corona except this single peculiarity, that (as was supposed) the spectrum showed no dark lines. Now that the dark lines have been seen, all doubt seems finally removed. As Janssen said in the letter containing the discovery, 'the atmospheric theory is disposed of (*tranchée*), and we must recognise in the corona a circumsolar phenomenon containing effects of radiation, absorption, and reflection of light,' which it must be the business of future eclipse observers to analyse in detail.

During the eclipse of July 1878 the corona was found to extend to at least seven or eight millions of miles from the body of the sun.

It will be seen, in the chapter on 'Meteors and Comets,' how important a bearing the meteor theory of the corona (that is, of a portion of its light) has upon the history of the solar system. It has been

partly for this reason that I have here briefly considered the matter; but there is another and a most important relation in which these views must be regarded.

We know that the sun is the sole source whence light and heat are plentifully supplied to the worlds which circle around him. The question immediately suggests itself—Whence does the sun derive those amazing stores of force from whence he is continually supplying his dependent worlds? We know that, were the sun a mass of burning matter, he would be consumed in a few thousand years. We know that, were he simply a heated body, radiating light and heat continually into space, he would in like manner have exhausted all his energies in a few thousand years—a mere day in the history of his system. Whence, then, comes the enormous supply of force which he has afforded for millions on millions of years, and which he will doubtless continue to afford for at least as long a time as the worlds which circle around him have need of it—in other words, for countless ages yet to come?

Now there are two ways in which the solar energies might be mantained. The mere contraction of the solar substance, Helmholtz tells us, would suffice to supply such enormous quantities of heat, that if the heat actually given out by the sun were due to this cause alone, there would not, in many thousands of years, be any perceptible diminution of the sun's diameter. Secondly, the continual downfall of meteors upon the sun would cause an emission of heat. But though the sun's increase of mass from this cause

would not be rendered perceptible in thousands of years, either by any change in his apparent size or by changes in the motions of his family of worlds, yet the supply of heat obtainable in this way can be but small compared with the sun's emission of heat. This follows from the limits between which Leverrier has shown that the total mass of the meteors of our system must certainly lie.[1]

It seems far from unlikely that both these processes are in operation at the same time. Certainly the latter is, for we know, from the motions of the meteoric bodies which reach the earth, that myriads of these bodies must continually fall upon the sun. If the corona and zodiacal light are really due to the existence of flights of meteoric systems circling around the sun, or to the existence in his neighbourhood of the perihelia of many meteoric systems, then there must be a supply of light and heat from this source, though not nearly sufficient to account for the solar emission.

It is worthy of notice, however, that the association between meteors and comets has some bearing on this question. We know that the most remarkable characteristic of comets is the enormous

[1] Undue stress has been laid upon the probable change in the length of the year, owing to the downfall of meteors upon the sun's mass. It is forgotten that the crowded meteors forming the solar corona are *already* within the earth's orbit, and therefore already produce their full effect on the length of the year. The subsidence of all these bodies at once upon the sun would not affect the length of the year, though it would lead to certain modifications in the secular perturbations of the earth's orbit in figure and position.

diffusion of their substance. Now in this diffusion there resides an enormous fund of force. The contraction of a large comet to dimensions corresponding to a very moderate mean density would be accompanied by the emission of much heat. The question is worth inquiring into, whether we can indeed assume that all meteors which reach our atmosphere are solid bodies. Some may be of cometic diffusion. But, be this as it may, it is certain that a large portion of the substance of every comet is in a singularly diffused state. Since the meteoric systems circling in countless millions round the sun are, in all probability, associated in the most intimate manner with comets, we may recognise in this diffusion, as well as in the mere downfall of meteors, the source of an enormous supply of light and heat.

Lastly, turning from our sun to the other suns, which shine in uncounted myriads throughout space, we see the same processes at work upon them all. Each star-sun has its coronal and its zodiacal discs, formed by meteoric and cometic systems; for otherwise each would quickly cease to be a sun. Each star-sun emits, no doubt, the same magnetic influences which give to the zodiacal light and to the solar corona their peculiar characteristics. Thus the worlds which circle round those orbs may resemble our own in all those relations which we refer to terrestrial magnetism, as well as in the circumstance that on them also there must be, as on our own earth, a continual downfall of minute meteors. In those worlds, perchance, the mag-

netic compass directs the traveller over desert wastes or trackless oceans; in their skies, the aurora displays its brilliant streamers; while, amid the constellations which deck their heavens, meteors sweep suddenly into view, and comets extend their vast length athwart the celestial vault.

CHAPTER III.

THE INFERIOR PLANETS.

In considering the habitability of various portions of the solar system, we have to draw a marked distinction between the planets which travel within the orbit of the earth and those which lie beyond its range. So far, indeed, as our belief in these orbs being inhabited is concerned, we may apply the same processes of reasoning to one set of planets as to the other. Until it has been demonstrated that no form of life can exist upon a planet, the presumption must be that the planet is inhabited. But it is impossible to contemplate the various members of our solar system without being led to consider their physical habitudes rather with relation to the wants of such creatures as exist upon our own earth, than merely with reference to the existence of life of some sort upon their surface. Viewing Venus and Mercury in this way, we have a different set of relations to deal with than we find among the outer planets. We are struck at once with the marked effects which seem associable with their comparative proximity to the sun's orb. This feature and the shortness of their period of revolution—that is, of their

year—are the characteristic peculiarities we have to deal with.

I would willingly pay some attention here to the story of Vulcan, the planet which has been supposed to circle yet more closely than Mercury around the centre of our system, were it not that I regard the existence of this planet as utterly unlikely.

Mercury circles around the sun in the brief period of eighty-eight days, or rather less than three of our months. So that, if the planet has seasons, these must be severally about three weeks long. His distance from the sun varies between somewhat wide limits, owing to the eccentricity of his orbit. When he is nearest to the sun, he receives ten and a half times more light and heat from that luminary than we do; but when he removes to his greatest distance, the light and heat he receives are reduced by more than one-half. Even then, however, the sun blazes in the skies of Mercury with a disc four and a half times larger than that which he presents to the observer on earth.

Undoubtedly these peculiarities, the shortness of the Mercurial year, and the immense amount of light and heat poured by the sun upon the planet, are circumstances which do not encourage, at first sight, the belief that any creatures can subsist upon this planet resembling those with which we are familiar. We see at once that all forms of vegetation in Mercury must differ in a very striking manner from those which exist upon the earth, because their structure has to be adapted to much more rapid changes of temperature.

And the existence of a totally distinct flora suggests at once the belief that animal life on Mercury must be very different from what we see around us.

Let us, however, proceed a few steps farther.

It has been found that Mercury rotates upon his axis, and if we may put faith in the observations of Schröter, the Mercurial day is only a few minutes longer than our own. But though the fact of the planet's rotation has been observed, it has not been found possible to determine in what position the axis of rotation lies. It has been said that the planet's equator is much more inclined than the earth's to the plane in which the planet travels; but little reliance can be placed on the evidence which has been adduced in favour of this view.

We are thus left altogether in doubt as to the nature of the Mercurial seasons. That the planet has seasons of some sort we are certain, because even if the axis were so placed that perpetual spring reigned upon the planet—I mean, that the days and nights were at all times and in all places equal—yet his varying distance from the sun would give changes of temperature quite as marked as those which characterise our seasons in England, and very much more marked than those known in tropical regions. Of course, if this is the actual arrangement, there are different climates in different parts of the planet. Near his poles the sun, though visible for half the Mercurial day, attains yet but a low elevation above the horizon; just as he does on a spring day within our own polar

circles. At the equator the sun passes day after day to the zenith, and pours down upon the planet an amount of light and heat far exceeding the light and heat of our tropical climates. A sun immediately overhead, and showing a diameter varying from more than twice to more than three times that of our sun, must be a noble and may be a terrible phenomena in the skies of Mercury.

There is yet another arrangement by which, to a portion of the planet, at any rate, the Mercurial seasons might be tempered. If his axis is so placed that what would be the winter season were his orbit not eccentric takes place, for one hemisphere, when the planet is nearest to the sun, then undoubtedly it may very well happen (the inclination of his axis being suitably adjusted) that this so-called winter season is the warmest part of the year for that hemisphere. In this case there would be the least possible violence in the succession of the Mercurial seasons for that hemisphere. But in the other hemisphere the seasonal changes would be correspondingly intensified.

In either of these cases, it is readily conceivable that even forms of life resembling those we are acquainted with on earth might exist on Mercury, and this without any special provision for tempering the great heat and light of the sun. Those regions which correspond to our temperate and tropical zones would indeed scarcely be habitable; but the polar regions of the planet would not form a disagreeable abode.

If, however, the equator of the planet is very much

inclined to the plane in which Mercury travels, it cannot be doubted that no form of life known upon earth can possibly exist upon Mercury, *without* some special arrangements for tempering the seasonal changes. This will appear when we come to deal with the effect of the great inclination which some astronomers have ascribed to the equator of Venus; and therefore we need not consider the relation with regard to Mercury, respecting whose axial inclination no trustworthy information has hitherto been obtained.

It remains for us to consider what sort of provision may have been made to temper the great heat poured by the sun upon Mercury.

The climate of a planet, considered generally, is largely influenced by the nature of the planet's atmosphere. We have very clear evidence on this point, in the effects which we notice on our own earth. If we ascend to the summit of a lofty mountain, we find the air much colder than at its base. In India, though the full heat of a tropical sun is poured day after day upon the snowy summits of the Himalayas, yet the air continues colder than in the bitterest midwinter weather experienced by us in England. Not that the solar rays have no power. The heat is, in reality, even greater than on the plains, because it has not been intercepted by vapour-laden air. But the air itself is not heated. Owing to its extreme rarity and dryness, it neither impedes the passage of the sun's heat to the earth, nor prevents the return of that heat from the earth by radiation or reflection; and this

very fact, that it does not impede the passage of heat, means nothing else than that the air does not become heated.[1]

We have, then, so far as a rare atmosphere is concerned, two points to dwell upon—the readiness with which such an atmosphere permits the sun's heat to reach the surface of a planet, and the readiness with which it permits the planet's heat to pass away into space. Now we might feel doubtful which of these two effects was chiefly to be regarded, were it not that on our own earth we have experience of the effects of a very rare atmosphere. We know that the climate of very elevated regions is relatively much cooler than that of places on the plain. Thus we learn that the direct heating powers of the sun are not so much to be considered, in judging of the climate of any region, as the quality of the atmosphere.

Yet we must not deceive ourselves by inferring that mere rarity of atmosphere can compensate fully for an increased intensity of solar heat. It is not

[1] The following passage, quoted by Prof. Tyndall from Hooker's 'Himalayan Journals,' illustrates the peculiarities referred to above: 'At 10,000 feet, in December, at 9 A.M., I saw the mercury mount to 132°, while the temperature of shaded snow hardly was 22°. At 13,100 feet, in January, at 9 A.M., it has stood at 98°, with a difference of 68·2°, and at 10 A.M., at 114°, with a difference of 81·4°, whilst the radiating thermometer on the snow had fallen at sunrise to 0·7°.' Such observations as these are well worth studying. It is interesting to consider that at the summit of the highest peaks of the Himalayas the mid-day heat due to the sun must sometimes be near if not above the boiling point corresponding to those places, since water would boil on Mount Everest at a temperature of little more than 160°.

true that the climate of a place on the slopes of the Andes or the Himalayas corresponds to that of a region on the plain which has an atmosphere equally warm. The circumstances are, in fact, wholly different. On the plain there is, it is true, the same amount of heat in the case supposed; but the air is denser and more moisture-laden: the nights are warmer because the skies are less clear and the heat escaping from the earth is intercepted by clouds or by the transparent aqueous vapour in the air; and, lastly, there is not so great a contrast between the warmth of the air and the direct heat of the solar rays.

If the atmosphere of Mercury, therefore, be excessively rare, as some have supposed, so as to afford an Alpine or Himalayan climate in comparison with the tremendous heat we should otherwise ascribe to the climate of the planet, there would by no means result a state of things resembling that with which we are familiar on earth. We must not, in our anxiety to people Mercury with creatures such as we know of, blind ourselves to the difficulties which have to be encountered. We cannot thin the Mercurial air, without adding to the direct effects of the sun upon the Mercurial inhabitants. Whether in this way we increase the habitability of the planet may be doubted, when we consider that the direct action of the sun's rays upon the tropical regions of Mercury, thus deprived of atmospheric protection, would produce a heat four or five times greater than that of boiling water. It will hardly be thought that the intense cold in the

shade, or during the Mercurial night, would compensate for so terrible a heat. In fact, this view of the Mercurial climate would lead us to find a close resemblance between the inhabitants of the planet and the unfortunates described by Dante as doomed

A sofferir tormenti e caldi e gieli.

It would seem hard to believe in the existence of any organised forms under such conditions, unless perhaps such 'microscopic creatures, with siliceous coverings,' as Whewell proposed to people Venus with.

However, we have yet to consider whether an atmosphere of a different sort might not be better suited to the requirements of Mercury. We have seen the effects of a rare atmosphere; let us inquire into those which might be ascribed to a dense one.

The ordinary effect of a dense atmosphere we know to be an increase of heat, which is certainly not what we require in the case of Mercury. Nor are we familiar with any region upon our earth in which a dense atmosphere produces a contrary *climatic* effect; so that we have no analogy to support us in the belief that possibly a dense atmosphere might, under particular circumstances, serve to guard a planet from the solar rays. It seems possible, however, that an atmosphere might be so constituted as to remain almost constantly loaded with heavy cloud-masses. In this case it by no means follows that such effects would follow as we ordinarily associate with a moisture-laden atmosphere. Up to a certain point, doubtless, the

increase of moisture in the air tends to an increase of warmth; because the aqueous vapour exercises a greater effect in preventing the escape of heat from the earth than in guarding the earth from the solar rays. And, as I have said, the only *climatic* effect we can associate with the frequent presence of large quantities of aqueous vapour in the air, or therefore with an ordinarily clouded state of the sky, is that of a general increase of heat. But, just as we know that a cloudy day is not necessarily nor even commonly a warm day, it may well be that an atmosphere so dense as to be at all times cloud-laden serves as a protection from the sun's intense heat. So that, instead of assigning dense atmospheres exclusively to the more distant planets, as some astronomers have done, we might be led to see in an envelope of great density the means of defending the inhabitants of Mercury and Venus from the otherwise unendurable rays of their near neighbour the sun.

Although Mercury is not a planet which can be satisfactorily examined with the telescope, yet, so far as can be judged from his aspect, his atmosphere is in reality much denser than our earth's, and loaded with cloud-masses of enormous extent. Still the evidence on these points is far from satisfactory; and there is one peculiarity of the planet which does not accord with this view of the constitution of his atmosphere. Undoubtedly, if the light we receive from Mercury came from a cloudy envelope, at would be more brilliant than the light we should receive from the surface of con-

tinents and oceans. In fact, the most brilliant light we could receive from a globe of a given size, placed at a given distance from the sun, would be that which would be reflected were such a globe covered with clouds. Now there can be no doubt whatever that Mercury does not reflect the same proportion of light from his surface that some of the planets do. He would be, when favourably situated, the brightest of all the planets, were this so;[1] though, seen as he always is, on the bright background of a full twilight sky, he would not make so striking an appearance as Jupiter does when in opposition. This, however, is not the case. I remember being much struck by the superior light of Jupiter, on the afternoon of February 23, 1868, when the two planets were very close together, Mercury being nearly at his brightest, whereas Jupiter, then near conjunction, was considerably less

[1] Placing Mercury in perihelion and at his elongation, we get a half disc, the planet about 90,000,000 miles from us, and about 30,000,000 from the sun, his diameter about 3,000 miles. Now, if we wish to compare the light he then sends us with that of Jupiter at his brightest, on the assumption of equal reflective powers, we must take Jupiter at a distance of about 360,000,000 miles from us, and about 450,000,000 miles from the sun, showing a full disc, his diameter about 90,000 miles (I put all the numbers *round*, for convenience of calculation). We find, then, that the ratio of Mercury's light to Jupiter's is

$$\frac{1}{2} \cdot \frac{(3,000)^2}{(90,000,000)^2 \times (30,000,000)^2} : \frac{(90,000)^2}{(360,000,000)^2 \times (450,000,000)^2}$$

or, $\frac{1}{2}\,(4)^2\,(15)^2 : (30)^2$, or exactly 2 to 1.

The observation above cited is sufficient to prove that a very different state of things actually prevails; in other words, that the reflective powers of the two planets are very different: unless, indeed, Jupiter shines in part by inherent light.

bright than when in opposition. Venus was close by, and outshone both Mercury and Jupiter.

It seems difficult, therefore, to believe that the light of Mercury comes from a cloudy envelope. But there is still one supposition which may restore our belief in the habitability of the planet by creatures not very different from those which inhabit our earth. If it has a double cloud envelope, the upper like our cirrus clouds, less compact than the lower, and permitting a portion of the sunlight to pass through, it is possible that the lower cloud-layer would be seen partly in shadow. I must admit that the explanation is not quite satisfactory, because, just as much light as the outer clouds intercepted they would reflect; still, it is conceivable that the usual arrangement of these clouds may be such that to us, who do not look at the planet in the direction in which the sun's rays fall, but somewhat aslant, the shadows of the upper clouds upon the dense and compact lower envelope may be rendered in large part visible.

After all, the reader may prefer the view which recognises in the polar regions of Mercury places suitable for organic existences, while the equatorial and neighbouring regions are zones of fire, whose dangers the bravest Mercurials, the very Livingstones upon that planet, would not dare to face. We may picture to ourselves, on this view, the various contrivances by which the inhabitants of the two polar (that is, in reality, temperate) circles manage to communicate. There may be regions where favouring

circumstances narrow the uninhabitable zone so much that the inhabitants of one polar circle may travel to the other (or, at least, cross the most dangerous portion of the hot zone) in the course of the Mercurial night. Or perhaps tunnels may be run, or sheltered cuttings made, along which the voyage may be made in comparative safety. Ocean communications there can be none, if the Mercurial skies are clear, since the sun's heat on the tropical zone would suffice to boil away any water which might find its way there.

Certainly, the smallness of the planet and the diminished effects of gravity upon its surface, would tend to make communication much easier, and the construction of protective tunnels or cuttings a comparatively light task. What the exact force of gravity at the surface of Mercury may be we do not know, because our means of determining the mass of the planet are not so satisfactory as in the case of the other primary members of the solar system. If Mercury had a satellite, we could tell his weight at once. If he were as large as Venus, we could tell his weight by observing his effect in disturbing the motions of that planet. As it is, the only means we have of weighing Mercury is the observation of his effect in disturbing any comet which may pass near him. In this way the planet has been weighed, but the balance thus employed is not a satisfactory one altogether, because we are not quite certain how much of the disturbance of a comet when near Mercury is due to the planet's attraction. Formerly it was supposed that the mean density of Mercury is equal to

that of lead; but from the perturbations of Encke's comet in Mercury's neighbourhood, astronomers have been led to the conclusion that the density of the planet is not more than one-sixth greater than our earth's. It follows that as his diameter is little more than 3,000 miles, our earth is about fifteen times as heavy as Mercury. Gravity at his surface is such that a pound weight of ours would weigh rather less than seven ounces of Mercury. Hence the creatures which seem to us most unwieldy—the elephant, the hippopotamus, and the rhinoceros, or even those vast monsters, the mammoth, the mastodon, and the megatherium, which bore sway over our globe in far-off eras—might emulate on Mercury the agility of the antelope or the greyhound.

There can be no doubt that where gravity acts so feebly, all engineering operations would be rendered very much simpler—bridges could have a wider span, and yet be stronger than our terrestrial ones, buildings could be loftier and yet be raised more easily, and transit of all sorts would be effected much more readily, while at the same time the distances to be traversed are very much less than on our earth, since the surface of Mercury is little more than one-seventh of the earth's.

The peculiarities which characterise Venus are for the most part similar in kind to those we have had to consider in the case of Mercury. But at the outset of our inquiries into the physical habitudes of this most beautiful planet, we must point to the striking resemblance which it bears, in some respects, to our own

earth. So far, indeed, as telescopic and physical researches have yet led us, the planet Mars, as we shall presently see, appears to exhibit habitudes more closely corresponding to those we are apt to consider essential to the wants of living creatures. But in size, in situation, and in density, in the length of her seasons and of her rotation, in the figure of her orbit, and in the amount of light and heat she receives from the sun, Venus bears a more striking resemblance to the earth than any orb within the solar system. In fact, there is no other pair of planets between which so many analogies can be traced as between Venus and the earth. Uranus and Neptune are similar in many respects, but they differ in at least as many. Jupiter and Saturn are, in a sense, the brother giants of the solar scheme, while the dwarf orbs Mars and Mercury present many striking points of similarity; but between neither of these pairs can we trace so many features of resemblance as those which characterise the twin planets Venus and Terra, while the features of dissimilarity in either pair are perhaps even more obvious than the points of resemblance. Had Venus but a moon as the earth has, we might doubt whether, in the whole universe, two orbs exist which are so strikingly similar to each other.

And here we may pause for a moment to consider one of the most perplexing enigmas that has ever been presented to astronomers. Are we indeed certain that Venus has no moon? The question seems a strange one, when it is remembered that year after year Venus

has been examined by the most eminent modern observers, armed with telescopes of the most exquisite defining power, without any trace of a companion orb being noticed. Nor indeed can any reasonable doubts be entertained respecting the moonless condition of Venus by those who appreciate the character of modern telescopic observations. And yet, if I had begun this paragraph by stating the evidence in favour of the existence of a satellite, I believe that nearly every reader would have come to the conclusion that most certainly the Planet of Love has an attendant orb. They are not amateur observers only who have seen a moon attending on Venus, but such astronomers as Cassini and Short, the latter with two different telescopes and four different eye-pieces. Four times, between May 3 and 11, 1761, Montaigne saw a body near Venus which presented a phase similar to that of the planet, precisely as a satellite would have done. From these observations M. Baudouin deduced for the new star a diameter of about 2,000 miles, and a distance from Venus nearly equal to that which separates the moon from the earth. In March 1764, again, Rödkier saw the enigmatical companion; Horrebow saw it a few days later; and Montbaron saw it in varying positions on March 15, 28, and 29. Lastly, Scheuten, who witnessed the transit of Venus in 1761, declares that he saw a satellite accompany Venus across the face of the sun. So that we cannot be greatly surprised that some are still disposed to believe in the existence of a satellite of Venus.

There is little occasion to dwell upon Venus's moonless condition, because the inferior planets are much less affected by the want of a moon than a superior planet would be. The service rendered by our own moon, as a luminary of the night, is the least important work she does in our behalf. It is as the chief regulator of the tides that the moon befriends us most usefully. Now Venus has no need of lunar tides. Assuming that she has oceans such as those which exist upon the earth, her solar tides must be about two and a half times as high as the solar tides raised in our own oceans. Now, since our lunar tidal wave is about two and a half times as high as the solar one, we have tides ranging between the highest spring tides, which are three and a half times as high as the solar tide alone, and the lowest neap tides, which are only one and a half times as high as the solar wave. Venus has constant tides, therefore, corresponding very closely to the mean tides on our own earth; and therefore perfectly well adapted to subserve all the purposes which our tides render us, only with less variety in their mode of operation. Mercury also has sufficiently high solar tides, supposing he has extensive oceans (which may reasonably be questioned), since the smallness of his dimensions (tending of course to diminish the difference of action, on which the sun's tidal influence depends) is fully compensated by his great proximity to that orb.

Venus has a year of 224 days 17 hours, very nearly, and her distance from the sun, which varies little during the course of a year, is somewhat less than three-fourths

of that which separates the sun from us. Her day is about thirty-five minutes shorter than ours, and her globe somewhat smaller than the earth's.

It is clear that, merely in the greater proximity of Venus to the sun, there is little to render at least a large proportion of her surface uninhabitable by such beings as exist upon our earth. The sun, as seen in her skies, has a diameter one-third larger than he presents to us; and his apparent surface dimensions, on which of course his heating and illuminating powers depend, are greater in the proportion of about sixteen to nine. This undoubtedly would render his heat almost unbearable in the equatorial regions of Venus, but in her temperate and sub-arctic regions a climate which we should find well suited to our requirements might very well exist; while her polar regions might correspond to our temperate zones, and be the abode of the most active and enterprising races existing upon her surface.

Here, however, we have been supposing that Venus has seasons resembling our own in character—in other words, that her axis of rotation is inclined at about the same angle to the plane in which she travels. Observations have been made, according to which a very different state of things would appear to prevail. It has been said, on the authority of observers of some eminence, that her axis is inclined only 15° to the plane of her orbit.[1] If this is really the case, a number of

[1] If the observations of De Vico may be trusted, the inclination of Venus, though less than 75°, is still so considerable (about 55°)

singular and somewhat complicated relations are presented, the result of which it may be interesting to exhibit to the reader.

In the first place, the arctic regions of Venus extend within fifteen degrees of her equator (if the axis is really bowed as supposed), while the tropics extend within fifteen degrees of her poles—so that two zones, larger by far than the temperate zones of our earth, belong both to her arctic and to her tropical regions. It is difficult to say whether her equatorial, her polar, or her arctico-tropical regions would be, to our ideas, the least pleasing portion of her globe.

An inhabitant of the regions near either pole has to endure extremes of heat and cold such as would suffice to destroy nearly every race of living beings subsisting upon the earth. During the summer the sun circles continually close to the point overhead, so that, day after day, he pours down his rays with an intensity of heat and of light exceeding nearly twofold the mid-day light and heat of our own tropical sun. Only for a short time, in autumn and in spring, does the sun rise and set in these regions. A spring or autumn day, like one of our days at those seasons, lasts about twelve hours; but the sun attains at noon, in spring or autumn, a height of only a few degrees above the horizon. Then presently comes on the terrible winter, lasting about three of our months, but far more striking in its characteristics even than the long winter night of our polar

as to justify the general conclusions deduced in the following paragraphs.

regions. For, near our poles, the sun approaches the horizon at the hour corresponding to noon ; and though he does not show his face, he yet lights up the southern skies with a cheering twilight glow. But during the greater part of the long night of Venus's polar regions, the sun does not approach within many degrees of the horizon. Nay, he is farther below the horizon than the midnight winter sun of our arctic regions. Thus, unless the skies are lit up with auroral splendours, an intense darkness prevails during the polar winter which must add largely to the horrors of that terrible season. Certainly, none of the human races upon our earth could bear the alternations between these more than polar terrors and an intensity of summer heat far exceeding any with which we are familiar on earth.

Let us see whether the equatorial regions are more pleasing abodes.

In these parts of Venus there are two summers, corresponding to the spring and autumn of the polar regions. At these seasons the sun rises day after day to the point overhead, and the weather corresponds for awhile to that which prevails in the tropical regions of our own earth. But between these seasons the sun passes away alternately to the northern and southern skies. During the season corresponding to summer he is above the horizon nearly throughout the 23 hours of Venus's day ; [1] but he attains no great eleva-

[1] On the equator itself, as on our own, the day is always equal in length to the night. The above account corresponds to a place near the borders of the equatorial zone.

tion, travelling always in a small circle close around the northern pole. During the season corresponding to winter he is above the horizon only a very short time each day, and is always close to the south, attaining only an elevation of a few degrees at noon. Thus we have the following curious succession of seasons: at the vernal equinox a summer much warmer than our tropical summers; about 56 days later, or at the summer solstice, weather resembling somewhat the spring of our temperate zones, only that the night is exceedingly short; yet 56 days later there is another summer, as terrible as the former; and lastly, at the winter solstice, the days are shorter and the cold probably more intense than in the winter of places near our Arctic Circles. In such regions the contrasts, rather than either of the extremes of climate, would be most trying to terrestrial races; and it is scarcely too much to say that no races subsisting upon our earth could possibly endure such remarkable changes, succeeding each other so rapidly.

Lastly, the beings who inhabit the wide zones which are at once tropical and arctic have climates ranging between the two limits just considered. If they are near the equatorial regions they suffer from all the vicissitudes of the equatorial climate, with this further tribulation, that in midwinter they do not see the sun even at mid-day—a circumstance by no means compensated (according to our ideas) by the fact that near the summer solstice the sun does not set. If they are near the polar regions, they have a summer even

more terrible than the polar summer, and a winter scarcely less dreary and bitter.

Fortunately for our belief in the habitability of Venus, astronomers are far from accepting with confidence the assertions of those observers who have assigned to Venus an inclination so remarkable. If her inclination at all resembles the earth's, there is every reason to believe that her physical habitudes also resemble those of the earth. In this case, the argument from analogy, presented in the opening chapter of this work, seems to force upon us the conclusion that she is inhabited; while we may believe, though perhaps with less confidence, that a close resemblance subsists between the creatures which people her surface and those with which we are acquainted.

We have no direct evidence, indeed, on which to ground our belief that the great proximity of Venus to the sun may not be accompanied by any very remarkable peculiarities in the characteristics of her climate. But we have an indirect argument of some strength. If Venus is much nearer than the earth to the sun, the earth, in turn, is much nearer to the sun than Mars is. Yet, as we shall see in the next chapter, we have clear evidence from telescopic observation, and still clearer evidence in the results of spectroscopic research, that the climatic arrangements on Mars do not differ in any remarkable degree from those of our own earth. It would follow, therefore, as at least probable, that a similar resemblance prevails between the climate of the earth and that of Venus. So

that, despite the claim which Dr. Whewell has put in for microscopic animalcules with siliceous coverings as the sole inhabitants of Venus, I can find no reason (if the abnormal axial inclination above considered is once disproved) for denying that she may be the abode of creatures as far advanced in the scale of creation as any which exist upon the earth.

Gravity at the surface of Venus is so nearly equal to terrestrial gravity that the difference is altogether insufficient to introduce any noteworthy effects.

Venus is the only planet the extent of whose atmosphere has been carefully estimated. If Venus had no atmosphere, she would present, when horned, a semicircular convexity; whereas the refractive effects of an atmosphere, by causing the sun to illumine rather more than a full hemisphere, would tend to lengthen her horns. It has been found that her convexity when she is horned exceeds a semicircle, and from the observed extent of this excess, it has been calculated that her atmosphere is so far more extensive than ours as to make its refractive effects on a body near the horizon about one-third greater. So that, this being about the proportion in which the diameter of the sun as seen from Venus exceeds that which he presents to us, the inhabitant of Venus, like the inhabitant of our earth, sees the sun fully raised above the horizon at the moment when, but for reflection, his orb would be just concealed beneath it.

Of the constitution of the atmosphere of Venus we know little. The spectrum of her light shows the

dark lines which belong to the solar spectrum, and the Padre Secchi has noticed certain faint lines, which seem to indicate the presence of aqueous vapour in the atmosphere of the planet. But he scarcely gives satisfactory evidence that the lines he has thus seen were not due to the absorption exercised by aqueous vapour in our own atmosphere. The same observer finds, in the strengthening of the nitrogen lines near the F line of the spectrum, evidence that the atmosphere of Venus is constituted very similarly to the air we breathe.

On the whole, the evidence we have points very strongly to Venus as the abode of living creatures not unlike the inhabitants of earth. With the sole exception of the inclination, which has been, without sufficient evidence, assigned to the planet's equator, I can see nothing which can reasonably be held to point to an opposite conclusion. The strong light which the sun pours upon Venus need least of all be objected to, since, if there is one adaptative power which Nature exhibits more clearly than another, it is that by which the various creatures we are acquainted with are enabled to live in comfort under all degrees of light, from the obscurity in which the mole pursues his subterranean researches, to the blazing light of the noonday sun towards which (in fable, if not in fact) the eagle turns his unshrinking eyes.

There is one peculiarity which yet remains to be noticed. Many are disposed to find, in the beauty of the celestial objects which deck the skies of different

planets a certain proof that reasoning beings must exist who can appreciate the display. Surely the argument has very little force, since we know that myriads on myriads of ages must have passed, during which the glories of our own heavens were displayed, night after night, with none to regard them. The moon has passed through all her phases, the star of morning and of eve has shed its soft radiance upon the terrestrial landscape, Jupiter and Saturn have pursued their stately courses among the fixed stars, and the glories of those constellations which shine with equal splendour upon all the planets of the solar scheme have been displayed in all their unchanging magnificence, while as yet our earth was the abode but of hideous reptiles, or of yet more monstrous creatures in forest and in plain.

If this argument were really of force, doubtless there are no planets in the whole range of the solar system to which it might not be applied. Each has some special object of beauty in its heavens, which is not exhibited to the rest. Certainly Mercury and Venus are no exceptions to this rule. The inhabitant of Mercury sees in Venus an orb which, when favourably situated, far outshines in splendour the brightest of the planetary orbs seen in our skies. So far, indeed, as light-giving power is concerned, Venus must be no contemptible moon to the Mercurials when she is nearly in opposition. Our earth, too, with its companion moon, must form a noble object in the sky of Mercury, though, without telescopic aid, the moon perhaps may

not be separately visible. To the inhabitants of Venus, Mercury and the earth must be splendid objects. The former would not only appear much larger than to ourselves, but being seen almost as favourably as we see Venus, would form a much more striking object in the morning or evening skies of that planet. The earth, as seen by the inhabitants of Venus, must shine much more splendidly than Jupiter does in our skies. Our moon must be distinctly visible, so that, without the aid of any telescope, the inhabitant of Venus has such evidence of the Copernican theory as would suffice, if properly handled, to rout the ranks of the Ptolemaists, supposing there have ever been people in Venus who imagined the tiny globe they live upon to be the centre of the universe.

CHAPTER IV.

MARS, THE MINIATURE OF OUR EARTH.

It is singular that, among all the orbs which circle around the sun, one only, and that almost the least of the primary planets, should exhibit clearly and unmistakably the signs which mark a planet as the abode of life. We have examined Mercury and Venus, the only other orbs which belong like the earth and Mars to the scheme of the minor planets, and we have found little to guide us to any certain conclusion respecting their physical habitudes. When we pass beyond the wide gap which separates the minor planets from the giant members of the solar family, we shall find much to attract our admiration, much to force upon us the belief that these orbs have been created to be the abodes of even nobler races than those which subsist upon our earth; but we shall find little to justify us in asserting that they resemble the earth in those habitudes which seem essential to the wants of terrestrial races. The planet Mars, on the other hand, exhibits in the clearest manner the traces of adaptation to the wants of living beings such as we are acquainted with. Processes are at work out yonder in space which

appear utterly useless, a real waste of Nature's energies, unless, like their correlatives on earth, they subserve the wants of organised beings.

I would not indeed insist, as some have done, too strongly upon this argument. I know that on every side we see tokens of an exuberant activity in Nature, which, according to our ideas, may appear to savour of wastefulness. The cloud which has been raised by the solar energies from tropical seas, and which the winds have wafted over continents, may shed its waters on the sea or in the desert, where seemingly they are wholly wasted. Winds may spend their force apparently in vain. And in a thousand ways Nature's busy forces may be at work where we, in our short-sightedness, can see no useful purpose which they subserve.

But there is a marked distinction between such apparent instances of wasteful action, and the systematic processes which are taking place over the globe of Mars.

Upon our earth we can dimly trace out a necessity (depending upon the order which actually exists) for that which appears to resemble waste. We see, for instance, that if a country or a continent is to be provided with a due supply of rain, without supernatural intervention at every step of the process, that result can only be secured by what may be described as a random distribution, involving always what to us resembles waste. If, out of a thousand showers, ten only fall so as to be useful to the land, the useful rainfalls

serve to explain (so to speak) the seemingly wasted ones.

In the case of Mars we have no such explanation of the processes we observe, if we dismiss our belief that he is the abode of living creatures. For if Mars be, indeed, untenanted by any forms of life, then these processes, going on year after year and century after century, represent an exertion of energy which appears absolutely without conceivable utility. If one cloud out of a hundred of those which shed their waters upon Mars supplies in any degree the wants of living creatures, then the purport of those clouds is not unintelligible; but if not a single race of beings peoples that distant world, then indeed we seem compelled to say that in Mars at least Nature's forces seem wholly wasted.

Let us consider what astronomy has taught us respecting the ruddy planet.

The globe of Mars is about 5,000 miles in diameter, so that his linear dimensions bear to those of the earth the proportion of about 5 to 8. His surface, therefore, is less than that of the earth in the proportion of about 25 to 64, or more exactly (and more conveniently), the surface of the earth is $2\frac{1}{2}$ times as extensive as that of Mars.

The substance of Mars has an average density rather less than three-fourths of our earth's, or very nearly four times that of water. Thus gravity at his surface is much less than terrestrial gravity. It is even less, in fact, than gravity at the surface of Mercury,

insomuch that one of our pound weights placed at the surface of Mars would weigh but 6 oz. 3 dwts., instead of nearly 7 ounces, as on Mercury. I have already dwelt on the effects of such a relation as this, and shall have occasion, when describing the condition of Jupiter, to discuss the converse relation. But I may remark, in passing, how singular it is that we should be compelled to people the smallest planets with the largest inhabitants, if we wish to bring the inhabitants of different orbs to about the same scale of activity. A Daniel Lambert on Mars would be able to leap easily to a height of five or six feet, and he could run faster than the best of our terrestrial athletes. A man of his weight, but proportioned more suitably for athletic exercises, could leap over a twelve-feet wall. On the other hand, a light and active stripling removed to Jupiter would be scarcely able to move from place to place. On the sun his own weight would simply crush him to death.

Mars travels in an orbit of considerable eccentricity; in fact, the centre of his orbit is no less than 13,000,000 miles from the sun. Accordingly, the light and heat he receives from that luminary vary to an important extent. In fact, he gets about half as much heat and light again when in perihelion as when in aphelion. This circumstance affects to an important extent the climatic relations of his two hemispheres, as we shall presently see.

When Mars is at his mean distance from the sun, the light and heat he receives are less than ours in the

proportion of about 4 to 9. The length of his year also constitutes a noteworthy circumstance in which his habitudes differ from those of our earth. His year contains very nearly 687 of our days, so that each of the Martian quarters lasts about $5\frac{2}{3}$ of our months. But, owing to the eccentricity of his orbit, the winter and summer of the northern and southern hemispheres are not equal. The Martian day is nearly forty minutes longer than ours.[1]

His equator is inclined at an angle of about $27\frac{1}{4}$ degrees to the plane of his orbit, and as the corresponding inclination in the case of the earth is about $23\frac{1}{2}$ degrees, it will be seen that his seasonal changes do not differ much in character, so far at least as they depend on inclination, from our own.

The axis of Mars is so situated that the summer of his northern hemisphere occurs when he is at his greatest distance from the sun. The same relation holds in the case of the earth, the sun being 1,500,000 miles nearer to us in winter than in summer, whereas, to those who live in the southern hemisphere, he approaches nearer in summer than in winter. But the effects resulting from the relation in the case of Mars

[1] More exactly, the length of the Martian day is 24h. 37m. 22·7s. This estimate I have obtained by comparing pictures taken by Hooke in 1666, and by Dawes and Browning in 1866-69—taking precautions to secure that no complete rotation should anywhere be lost sight of. Kaiser obtained a period differing only one-tenth of a second from mine; but even this small discrepancy is removed when certain clerical errors in Kaiser's work (as his counting 1700 and 1800 as leap-years, and wrongly correcting for change of style) are removed.

must be very much more striking than those we recognise. For whereas the sun gives only one-fifteenth more heat to the whole earth in January than he does in July, the sun of Mars gives half as much light again in perihelion as in aphelion. The summer of the northern hemisphere of Mars must be rendered much cooler and the winter much warmer by this arrangement. On the other hand, the contrast between the summer and winter of the southern hemisphere is rendered more striking than it otherwise would be.

It is, however, the telescopic aspect of Mars rather than relations such as we have been dealing with that affords the most interesting evidence respecting the fitness of the planet to be the abode of living creatures. Although the least but one among the primary planets—a mere speck compared with Jupiter and Saturn—Mars has been examined more minutely and under more favourable circumstances than any object in the heavens except the moon. He does not approach us so closely as Venus, nor does his disc appear so large as Jupiter's, yet he is seen more favourably than the former planet, and on a larger scale, in reality, than the latter. In fact, whereas Venus is one of the most unsatisfactory of all telescopic objects, Mars is one of the most pleasing; and whereas Jupiter is always more than 380,000,000 of miles from us, Mars sometimes approaches us within less than 40,000,000 of miles.

Yet even this distance is enormous, and it affords high evidence of the skill with which modern tele-

scopes are constructed and used that astronomers should have been able to span that mighty gulf, and to bring from beyond it reliable information respecting the structure of so distant a world.

Such information has been brought, however, and is full of interest.

Viewed with the naked eye, the most remarkable feature Mars presents is his ruddy colour. In the telescope this colour is not lost, but instead of characterising the whole surface of the planet, it is confined to particular regions—the intermediate parts being for the most part darker, and of a somewhat greenish hue. But a noteworthy feature adds largely to the beauty of the picture presented by the globe of Mars. Two bright spots of white light are seen on opposite sides of his disc, presenting precisely such an appearance as we might imagine the snowy poles of our earth to exhibit to an astronomer on the planet Venus.

Towards the edge of the disc the ruddy and the greenish tracts are lost in a misty whiteness, which grows gradually brighter up to the very border of the planet. This peculiarity, as will be seen, is one of the most instructive features of the planet's aspect.

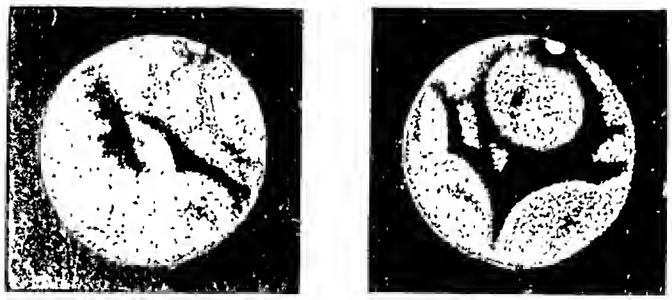
In August 1877 two minute moons were discovered which travel around Mars in about $30\frac{1}{4}$ hours and about $7\frac{2}{3}$ hours respectively.

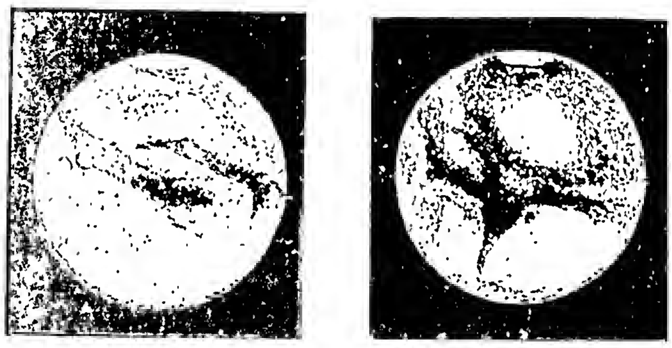
It was discerned, more than two hundred years ago, that the reddish spots on Mars, and the darker regions which lie between them, are not accidental or variable phenomena, but represent permanent peculiarities of

the Martian surface. Cassini, with one of those outrageously long telescopes which were used before the invention of achromatic refractors, was the first to discover this. But the ingenious Hooke seems to have obtained better views of Mars in 1666. At least, his pictures of the planet are the only ones taken in the seventeenth century in which I can recognise the now well-known aspect of the Martian continents and oceans.

Later, Maraldi and the Herschels, Arago, Secchi, Kunowski, Beer, and Mädler, and a host of other eminent astronomers, have not thought the study of this planet's aspect beneath their notice. Within the last few years, also, this work has been prosecuted by Dawes, Green, R. Trouvelot, and others. Dawes, whose acuteness of vision earned for him the title of the 'eagle-eyed,' took so many and such admirable views of the planet as to render it possible to form a globe of Mars. Sir William Herschel had chartered the planet, and Messrs. Beer and Mädler had made improved Martian maps; while Phillips had constructed two globes of Mars in which many features were presented. But Mr. Dawes's pictures of the planet were sufficient, when carefully compared, for the formation of a globe in which no large area of the planet should be left bare of details. He entrusted to me no less than twenty-seven drawings of Mars, the choicest specimens of a very large series, that I might chart the planet from them. From the study of his drawings the accompanying chart has been formed. Of the four illustrative views the upper were drawn by Mr. Trouvelot at Harvard, the

Mars in 1877 (*Trouvelot*).





Mars in 1877 (*N. Green*).

lower by Mr. Nath. Green. The chart of Mars, in which the darker parts of the planet are assumed to be seas and the lighter tracts continents, exhibits the results obtained from the study of the complete series. This chart is on Mercator's projection, and is inverted—the south polar regions, that is, are at the top—because the telescopes commonly used by observers exhibit inverted views of the celestial objects. At the top of the map we see the icy region which lies at the southern pole of Mars. Around that region is a sea unnamed in the maps. Then along the southern temperate zone there lie several tracts of Martian land, named after observers of the planet. These regions appear to form a continuous land-belt round the temperate zone; though there is some uncertainty on this point, owing to the fact that the coast-line is not often very distinctly visible. We now approach, however, a part of the map where all the features are thoroughly recognised and permanent. Next to the circle of land just described there is a nearly complete circle of water, one strip only of land connecting the equatorial continents of Mars with the south temperate zone of minor continents. Beginning at the eastern or left-hand extremity of the map, we have a long sea called Maraldi Sea parallel to which runs Hooke Sea, trending in a north-westerly direction, and so running into Dawes Ocean; still farther west are two vast islands, called Jacob Island and Phillips Island, between which runs Arago Strait. Beyond these islands lies De la

Rue Ocean, communicating by narrow straits with two strikingly similar seas. Here the zone of water ends, and we have only to note further respecting it that in De la Rue Ocean there is a large island, which presents so strikingly brilliant an aspect that it has been supposed to be covered (ordinarily) with snow. It has been called Dawes's Ice Island.

I now come to the most remarkable feature of the Martian geography—or perhaps I ought rather to say, *areography*. This is the great equatorial zone of continents. There are four of these. On the left of the map is Herschel I. Continent. Next is Dawes Continent, the largest of the four, and separated from the former by a long sea called Kaiser Sea. This sea is one of the most striking marks on the planet, and has been recognised from the earliest days of telescopic observation. It is connected towards the east with a flask-shaped sea, somewhat resembling the two which lie at the western extremity of the zone of water just described. At its northernmost end it turns sharply westward, and forms the southern boundary of Dawes Continent. Further west lies Mädler Continent, separated from Dawes Continent by a long strait, which runs almost directly north and south. Lastly, there is Secchi Continent, separated from Mädler Continent by Bessel Inlet and from Herschel Continent by Huggins Inlet. A large lake on the last-named continent is worthy of notice on account of its singular shape. It consists of two bell-shaped seas connected by a narrow and sharply curved strait.

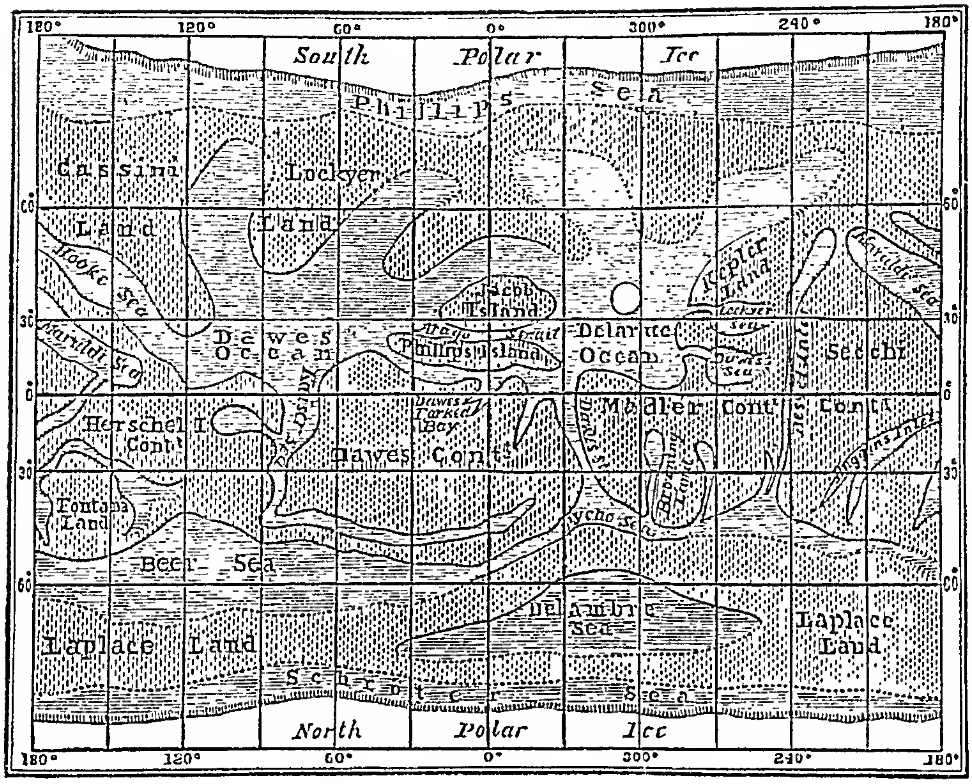


CHART OF MARS.

The northern half of Mars has not been so thoroughly examined as the southern, for a reason which will presently be mentioned. It is known, however, that, in all essential respects, it resembles the southern hemisphere. Next to the equatorial zone of continents there comes a zone of water, expanding at one point into Beer Sea, and at another into Tycho Sea. Then comes a zone of land, called Laplace Land, in which lies an enormous lake called Delambre Sea. Next is a narrow zone of water, called the Schröter Sea: and so we reach the north polar ice-cap.

I have been speaking of the spots on Mars as though they undoubtedly represented land and water. But many may be disposed to question the evidence we have on this point—to ask why the ruddy spots should be held to be continents or islands, and the greenish-coloured markings to be oceans, seas, and lakes. We know that for a long time after the invention of the telescope, astronomers called the darker portions of the moon, *seas*. They spoke of the Sea of Serenity, the Sea of Crises, the Sea of Humours, and so on; and we know now for certain that these dusky regions are not seas. It may be asked, therefore, how we can feel certain that the dark spots on Mars are oceans.

At first sight this question seems a difficult one to answer. The most powerful telescopes have been directed towards the moon, without affording any satisfactory information respecting the condition of its surface. Mars, therefore, which lies—even under

the most favourable circumstances—more than one hundred and sixty times farther from us than the moon, might be thought to be altogether beyond the reach of our telescopists—so far, at least, as any knowledge of the Martian surface is concerned. But one important distinction between Mars and the moon must be carefully attended to. The surface of the moon is always the same—no natural processes seem ever to take place over that scene of desolation, though the moon is exposed to contrasts of temperature, compared with which the distinction between the intensest heat of our summers and the bitterest cold of our winters seems altogether evanescent. But on Mars the case is certainly different. Whatever opinion we may form respecting Martian habitudes, whether we assume or not that Mars is the abode of any forms of animal life, there can be no question whatever that physical processes of change are taking place on a grand scale in that distant world. Many evidences of this can be at once adduced. We have spoken of the Martian features as constant. They differ, for instance, from the markings on Jupiter, which are as changeful as the aspect of our April skies. But though the same marking may have been seen by Hooke in 1666, by Maraldi in 1720, by Herschel in 1780, by Beer and Mädler in 1830–37, and by Dawes in 1852–65, yet it by no means follows that it is always visible when the part of Mars to which it belongs is turned towards us. A veil is sometimes drawn over it for hours or even days together. And this veil has nothing to do with

the distinctness or indistinctness with which our own atmosphere permits us to see the planet. A spot will be blurred and indistinct when a neighbouring marking is exhibited with unusual clearness.

Let us consider an instance of this peculiarity. On October 3, 1862, late in the evening, a part of Dawes Ocean, where it borders on Herschel Continent, was hidden from view. In place of the ordinarily dark aspect of this region, a faint, misty light, with ill-defined borders, was observable. As the evening progressed the outlines gradually became clearer, but at about half-past eleven the white light still continued to veil the outline of a part of Dawes Ocean. But Mr Dawes, observing Mars at a quarter past twelve, found that the process of clearing up noticed in the earlier part of the night had entirely lifted off the veil which concealed the coast-line. The remains of the misty light seen earlier are still to be detected in Mr. Dawes's drawing, but they have passed farther south, and no longer hide the shores of Dawes Ocean.

The Padre Secchi of the Collegio Romano states that he has often noticed similar appearances while observing Mars with the fine refractor in the observatory of that institution.

But yet another peculiarity of the same sort remains to be mentioned. Mars, as I have said, has his winter and summer seasons. Since we know the position of the Martian equator upon his surface, we can tell what season is in progress in either hemisphere at any given time. Now, it has been noticed that when it is winter

in one hemisphere, and therefore summer in the other, the former hemisphere is nearly always hidden from view by just such a veil as I have spoken of above.

I may remark, in passing, that this peculiarity has led many observers to form very erroneous impressions respecting the distribution of land and water over the surface of Mars. Seeing one hemisphere covered for weeks together with whitish light, they have concluded that there are no oceans there; and if they have no other opportunity of observing the planet, the mistaken impression remains, and is published to the world with all the authority of the observer's name.

Now, what is this veil which sometimes for a few hours or days, at others for months together, is drawn over the features of the Martian globe? Have we any terrestrial analogies by means of which we may interpret this phenomenon?

To answer these questions, let us conceive the case of an observer on Venus watching our earth. Would such an observer always see the features of this globe with equal distinctness? When heavy masses of cloud are drawn over a wide expanse of country—spreading often, as meteorologists record, for hundreds, and even thousands of miles—can we suppose that the astronomer on Venus could pierce through the veil? Since we cannot see the bright body of the sun through a dense cloud-veil, we may be certain that the observer on Venus cannot see the oceans and continents of our earth when thus cloud-shadowed. So far as the cloud-veil extends, the lands and seas of

this globe would be to him, at such a time, as though they were not.

Here, then, we have an argument from analogy for supposing that the veil, which from time to time conceals the Martian features, may resemble terrestrial cloud-banks. Let us next inquire whether there is anything in the behaviour of the Martian veil to justify this view.

It is clear that if we held the concealing medium to be of a cloudy nature, the disappearance of the features of the hemisphere which is passing through the Martian winter would indicate that in winter the Martian skies are more clouded than in summer. We know that this is the case on our own earth, that fogs and mists, clouds, rain, and snow, are phenomena far more frequently observed in winter than in summer. We know also why it is so. The cold winter air is unable to retain the aqueous vapour continually passing into it, and is thus forced to precipitate this vapour in one or other of the forms just named. Nor can we see any reason why the Martian atmosphere, supposing it to resemble our own, should not act in precisely the same manner. Thus we recognise, in the remarkable seasonal peculiarity above described, what seems to be the exact counterpart of processes recognised upon the earth.

Perhaps the reader may be disposed to inquire whether the clearing up of a portion of the Martian disc observed by Dawes admits of interpretation in a similar way. To this it may be replied that, from the observed position of the region in question, the Martian

time of day there must have been somewhere about noon, and about one o'clock in the afternoon (according to our terrestrial mode of reckoning) when Mr. Dawes observed the planet. It is no uncommon thing to see our terrestrial skies clear up soon after mid-day; and if the veil which conceals the Martian features is really cloudy, this is precisely what happened out yonder, forty millions of miles away from us, on the day in question.

I think the reader will at least concede that the explanation here given of these peculiarities is more natural than one which was put forward some time since by an eminent French astronomer. He urged that Martian vegetation, instead of being green like ours, is red; hence in the Martian summer, the surface, as seen by us, assumes a ruddy aspect, while the wintry hemisphere loses its ruddy tint. According to this interpretation, such changes as were noticed by Secchi would indicate the sudden blooming forth of Martian vegetation over hundreds of square miles of the Martian surface!

To the evidence already dealt with may be added that which is afforded by the whiteness of the disc of Mars near the edge. Knowing that the parts of Mars which thus appear concealed in mist are those where it is morning or evening to the Martians, we see a close analogy here to terrestrial relations, since our own skies are commonly more moisture-laden in the morning and evening than near mid-day.[1]

[1] In the 'Popular Science Review' for January 1869, I have in

I may here pause, in passing, to notice under what difficulties the observation of Mars is conducted by the terrestrial observer. To begin with, the sky must be exceptionally clear; and none but the practised observer knows how seldom there occurs what is called a good observing night.' Then it must be *a fine day for the Martians*, for clouds over Mars, or even an imperfectly clear atmosphere, must produce quite as bad an effect in spoiling the definition of Martian features as similar phenomena on earth. Again, Mars only comes into a favourable position once in every two and a quarter years, continuing to be well placed for only a few months. Thus it happens that, although Mars has been telescopically observed for more than two hundred years, the actual time during which he has been favourably placed for observation has been very much less; and taking into account all the requirements for good definition, it may be said that Mars has not been under really effective observation for more than a very few days.

Of course if we admit that the vaporous envelope which occasionally hides parts of Mars is aqueous, we must believe in the existence of oceans upon Mars. And from our knowledge of the appearance of our own seas, we should immediately recognise the greenish

dicated a subsidiary explanation of this peculiarity, founded on the probable shape of the Martian clouds. For the same reason that, near the horizon, our own cumulus clouds seem more closely packed than overhead, the Martians would see a clearer sky overhead than near the horizon. It follows at once that we should see best those parts of the surface of Mars which we look down upon in a nearly vertical direction, that is, the central parts of his disc.

parts of Mars as the Martian oceans, and look upon the ruddy parts as continents. We have seen that the behaviour of the various envelopes corresponds to that of our own clouds and fogs. But it might be thought possible that the vapours arise from fluids other than water; that, in fact, a state of things exists upon Mars wholly different from that which prevails upon our own earth.

A few years ago it would have been very difficult to disprove such an argument as this, however fanciful it may seem. But the wonderful powers of the spectroscope have been applied to this question, and there is no mistaking the results which have been obtained. We must premise that this is hardly a favourable case for the application of spectroscopic analysis, which (as available to the astronomer) deals most effectively with self-luminous objects. Still, there was a possibility that the light which comes from Mars might have been so acted upon by vapours in the Martian atmosphere that its spectrum would be affected in an appreciable manner.

Mr. Huggins examined Mars in 1864 without satisfactory results, but at the opposition of Mars in 1867 he was more successful. In the following description of his most striking observation I epitomise his account. On February 14 he examined Mars with a spectroscope attached to his powerful 8-inch refractor. The rainbow-coloured streak was crossed, near the orange part, by groups of dark lines agreeing in position 'with lines which make their appearance in the

solar spectrum when the sun is low down so that its light has to traverse the denser strata of our atmosphere.' To determine whether these lines belonged to the light from Mars or were caused by our own atmosphere, Mr. Huggins turned his spectroscope towards the moon, which happened to be nearer the horizon than Mars, so that the atmospheric lines would be stronger in the moon's spectrum than in that of the planet. But the group of lines referred to was not visible in the lunar spectrum. Hence it was clear that they belong to the Martian atmosphere, and not to ours.

I have said that these lines appear in the solar spectrum when the sun is shining through the denser strata of our atmosphere; so that the Martian atmosphere must contain at least those constituent vapours whose existence in our atmosphere causes the appearance of these lines in the solar spectrum. Hence there must be *some* similarity between the Martian atmosphere and our own. But we know from the researches of the Padre Secchi that it is the aqueous vapour in our air which causes the appearance of the lines in question. Hence there must be aqueous vapour in the Martian atmosphere.

The discovery at once justifies the title of the present chapter. Let us consider what a number of interesting results follow from it.

The water in the Martian air must be raised from seas and rivers upon the planet. These, therefore, consist of water, and not of other fluids. The two

white spots, then, on the Martian disc are no longer doubtful appearances. Before the discovery that water exists on Mars it was perhaps somewhat bold to pronounce that these spots certainly indicate the presence of ice-fields around the Martian poles, resembling those which exist around the poles of the earth. Sir William Herschel, indeed, with that confidence which he always showed when he had a trustworthy analogy to guide him, came to this conclusion on the strength of the correspondence between the changes of the two spots and the progress of the Martian seasons. But many astronomers felt that there was still room to doubt whether he could really speak of the spots as—

The snowy poles of moonless Mars.

Now, however, we know that they can be no other than snow-caps. Nay, if Mars were so far off that we could not distinguish these spots, we could yet, on the strength of what the spectroscope has taught us, pronounce confidently that his polar regions must be ice-bound.

Let us proceed a step or two farther. We have seen that there are oceans on Mars; we know that clouds and vapours arise from those oceans, and are wafted over his continents; and finally, we have learned that snow falls on the Martian polar regions. These facts are very interesting in themselves, but they indicate the occurrence of processes yet more interesting. The formation and the dissipation of clouds are among the most important of all the processes by which Nature arranges and modifies the temperature

of our earth. The heat of the sun's rays is used up, so to speak, in raising aqueous vapour from the surface of the ocean. Thus the air is rendered cooler than it otherwise would be, and this takes place just where coolness is most needed. But the aqueous vapour, once raised, is swept by the winds to other regions. So long as the air remains warm the aqueous vapour remains unchanged; but so soon as it has been carried to colder regions it is condensed into the form of a cloud or mist, and while changing to this form it parts with the heat which had turned it into vapour. Thus where heat is in excess, it is used up in forming aqueous vapour; and where heat is wanted, there the aqueous vapour distributes it.

We see, then, that on Mars there exists the same admirable contrivance for tempering climates which we find on our own earth.

But let us consider yet another office fulfilled by aqueous vapour. It not only serves to convey the heat from the warmer parts of the earth to those regions where heat is most needed; it forms clouds which serve to shelter the earth from the sun's heat by day, and to prevent the escape of the earth's heat by night, which also, in refreshing rains, 'drop fatness on the earth.' Now the clouds on Mars are certainly dissipated in some way, because, as I have said astronomers have repeatedly seen them disappear And doubtless, like our own clouds, they are often dissipated by the sun's heat. But we may take it for

granted that, like our terrestrial clouds, they are also often dissipated by falling in rain. Thus the Martian lands are nourished by refreshing rainfalls; and who can doubt that they are thus nourished for the same purpose as our own fields and forests—namely, that vegetation of all sorts may grow abundantly?

But yet again, the transit of clouds from place to place implies the existence of aërial currents. Clouds cannot indeed even form and be dissipated without occasioning wind-currents; and it need hardly be said that the Martian clouds could not be carried to his polar regions, there to fall in snow, unless the atmospheric currents on Mars were extensive and persistent. We see, then, that Mars has winds as our earth has. Doubtless his trade-winds are less marked than ours, because his surface rotates less rapidly than the earth's, his globe being much smaller, while his rotation-period is slightly greater. But he has less need for trade-winds, his oceans being so much less extensive than ours. No Columbus on Mars has ever needed the persistent breath of easterly winds to encourage him on his voyage to an undiscovered continent. Rather, the intricate navigation of the narrow Martian seas would be favoured by variable breezes. But the great purposes which the circulation of our own atmosphere subserves are subserved efficiently out yonder on Mars. The air is cleansed and purified, its thermal and electrical conditions are regulated, clouds are wafted from place to place; and, in fine, the atmosphere is rendered fit for all those purposes

for which, like our own, it has doubtless been created.

We may trace yet farther, however, the results which follow from the existence of aqueous vapour in the atmosphere of Mars. We see the polar snows aggregating in the Martian winter and diminishing in the Martian summer. And we know that, on our own earth, the increase and the diminution of the polar snows are processes intimately associated with the formation and maintenance of the oceanic circulation. Doubtless much yet remains to be done before that system of circulation will be fully understood. The rival views which have been maintained by Sir John Herschel and Captain Maury have served to throw a certain air of doubt over the theory of ocean currents.[1] But whether we ascribe the equatorial currents of our oceans to the trade-winds, with Herschel, or to differences of specific gravity, with Maury, we see that, in the first place, both causes operate in the case of Mars;

[1] If Herschel has completely overthrown Maury's theory, that currents are altogether due to differences of specific gravity, saltness, and so on, Maury has at least been as successful in overthrowing Herschel's theory, that the currents are due to the trade-winds. A theory more probable than either is, I think, that according to which the whole system of circulation is set in motion by the continual evaporation going on in equatorial seas. Thus, by a process resembling suction, an in-draught of cold water is caused, and this water coming from higher latitudes, where the earth's eastwardly motion is less, to lower latitudes, where the eastwardly motion is greater, produces the relatively cold and westwardly equatorial currents which exist in the Atlantic, Indian, and Pacific Oceans. Recent researches into the temperature of the deep sea have tended strongly to confirm these views, which I dealt with at some length in the second volume of my 'Light Science for Leisure Hours.'

and, secondly, that the submarine return-currents from our polar regions must, at any rate, be due to the presence of ice in the polar seas. So that undoubtedly the Martian oceans, so far as their peculiar conformation will permit, are traversed by currents in various directions and at various depths.

Then, lastly, there must be rivers on Mars. The clouds which often hide from our view the larger part of a Martian continent indicate a rainfall at least as considerable (in proportion) as that which we have on the earth. The water thus precipitated on the Martian continents can find its way no other wise to the ocean than along river courses.

As to the nature of these rivers, again, we may form conjectures founded on trustworthy analogies. The mere existence of continents and oceans on Mars proves the action of forces of upheaval and of depression. There must be volcanic eruptions and earthquakes modelling and remodelling the crust of Mars. Thus there must be mountains and hills, valleys and ravines, watersheds and watercourses. All the various kinds of scenery which make our earth so beautiful have their representatives in the ruddy planet. The river courses to the ocean, by cataract and lake, here urging its way impetuously over rocks and boulders, there gliding with stately flow along its more level reaches. The rivulet speeds to the river, the brook to the rivulet, and from the mountain recesses burst forth the refreshing springs which are to feed the Martian brooklets.

Who can doubt what the lesson is that all these

things are meant to teach us? So far, let it be remembered, we have been guided onwards by no speculative fancies, but simply by sober reasoning. But shall we recognise in Mars all that makes our own world so well fitted to our wants—land and water, mountain and valley, cloud and sunshine, rain and ice and snow, rivers and lakes, ocean-currents and wind-currents—without believing further in the existence, either now, or in the past, or in the future, of many forms of life? Surely, if it is rashly speculative to form such an opinion respecting this charming planet, it is to speculate still more rashly to assert that Mars is not, has never been, and never will be, tenanted by living creatures, or by any beings belonging to other than the lowest orders of animated existence.

CHAPTER V.

JUPITER, THE GIANT OF THE SOLAR SYSTEM.

Passing over the zone of asteroids, we come now to the noblest of all the planets—the giant Jupiter. If bulk is to be the measure of a planet's fitness to be the abode of living creatures, then must Jupiter be inhabited by the most favoured races existing throughout the whole range of the solar system. Exceeding our earth some 1,230 times in volume, and more than 300 times in mass, this magnificent orb was rightly selected by Brewster as the crowning proof of the relative insignificance of the earth in the scale of creation.

Or if we estimate Jupiter rather by the forces inherent in his system, if we contemplate the enormous rapidity with which his vast bulk whirls round upon its axis, or trace the stately motion with which he sweeps onward on his orbit, or measure the influences by which he sways his noble family of satellites, we are equally impressed with the feeling that here we have the prince of all the planets, the orb which, of all others in the solar scheme, suggests to us conceptions of the noblest forms of life.

The very symmetry and perfection of the system which circles round Jupiter have led many to believe that he must be inhabited by races superior in intelligence to any which people our earth. The motions of these bodies afford, indeed, to our astronomers a noble subject of study. Our most eminent mathematicians have given many hours of study to the phenomena which the four moons present to the terrestrial observer. But we can trace only the general movements of the satellites of Jupiter. Their minor disturbances, the effects of the varying influences which the sun and Jupiter exert upon them, and which the moons exert upon each other, must tax the powers of far abler mathematicians even than he who 'surpassed the whole human race in mental grasp.'

But after all, we must judge of Jupiter rather according to the evidence we have, and the analogies which are most directly applicable to the case, than according to fancies such as these. We know that the sun, which surpasses Jupiter in weight and volume even more than Jupiter surpasses the earth, is yet not the abode of life, so that mere size and mass must not be held to argue habitability. We know that many meteors and comets sweep through space more swiftly than the vast bulk of Jupiter, so that the energies indicated by mere velocity of motion, whether orbital or rotational, must be equally disregarded. Nor must we forget that, ages before men studied the motions of our own moon, she presented the same noble subject of study that she forms in our day for

an Adams, a Leverrier, or a Delaunay. Even now a thousand grand problems are presented to our men of science which escape their notice, and we might as reasonably argue that there must be creatures existing unperceived amongst us, who deal with these problems, as that, out yonder in space, there must be beings who study the complicated motions of the Jovian satellites.

Jupiter presents the following principal physical habitudes:—

He has a diameter of about 85,000 miles, or nearly 11 times as large as the earth's, a surface 115 times larger, and, as I have said, a volume more than 1,200 times larger. Gravity at his surface is about two and a half times as great as on our earth's, so that such creatures as exist around us would find their weight much more than doubled if they were removed to Jupiter. He lies more than five times farther from the sun than our earth, and the light and heat which he receives from that orb are reduced to about one-twenty-fifth of our supply. He rotates on his axis in rather less than ten hours (9 hours 55 minutes 26 seconds), so that the length of his day is considerably less than half of ours. His axis is nearly perpendicular to his orbit, so that there are no appreciable seasonal changes as he sweeps round the sun in his long year of 4,332½ days.

It will be convenient to consider, first, the probable influence of the great attractive power of Jupiter upon the dimensions of the various orders of living creatures existing upon his surface.

The grandeur of his orb naturally suggests, at first sight, the idea of beings far exceeding, both in might and bulk, those which live upon the earth. Old Wolfius was led to a similar conclusion in another way. I quote his quaint fancies as quaintly presented by Admiral Smyth. 'Wolfius,' says the genial sailor, 'not only asserts that there are inhabitants in Jupiter, but also shows that they must necessarily be much larger than those of the earth; in fact, that they are of the giant kind, and nearly fourteen feet high by *eye*-measurement. And thus he proves it. It is shown in optics that the pupil of the eye dilates and contracts according to the degree of light it encounters. Wherefore, since in Jupiter the sun's meridian height is much weaker than on the earth, the pupil will need to be much more dilatable in the Jovian creature than in the terrestrial one. But the pupil is observed to have a constant proportion to the ball of the eye, and the ball of the eye to the rest of the body; so that, in animals, the larger the pupil the larger the eye, and consequently the larger the body. Assuming that these conditions are unquestionable, he shows that Jupiter's distance from the sun, compared with the earth's, is as 26 to 5; the intensity of the sun's light in Jupiter is to its intensity on the earth in a duplicate ratio of 5 to 26.' The eyes of the Jovians and their dimensions generally must be correspondingly enlarged, and 'it therefore follows that even Goliath of Gath would have cut but a sorry figure among the natives of Jupiter. That is, supposing the Philistine's altitude to be some-

where between eight feet and eleven, according as we lean to Bishop Cumberland's calculation, or the Vatican copy of the Septuagint. Now, Wolfius proves the size of the inhabitants of Jupiter to be the same as that of Og, king of Bashan, whose iron camp-bed was nine cubits in length and four in breadth—or rather he shows, in the way stated, the ordinary altitude of the Jovicolæ to be $13\frac{819}{1440}$ Paris feet, and the height of Og to have been $13\frac{1296}{1440}$ feet. See his Works, vol. iii. p. 438.'

This exact determination of the dimensions of Jovian men would be very pleasing and satisfactory were it not that another line of argument guides us at least as conclusively to a very different view. If we are to assume that beings resembling men in all attributes except size actually exist on Jupiter, we might claim for these beings the power of moving from place to place as freely as we do, with quite as much reason as Wolfius claimed for them the same powers of vision that we possess. Proceeding according to this view, we are led to the conclusion that the *Jovicolæ* are pygmies about two and a half feet, on the average, in height. For we know that a man removed to Jupiter would weigh about two and a half times as much as he does on our own earth. He would thus be oppressed with a burden equivalent to half as much again as his own weight. This would render life itself an insupportable burden; and we have to inquire what difference of size would suffice to make a Jove-man as active as our terrestrial men. Now, the weight of bodies similarly

proportioned varies as the third power of the height; for example, a body twice as high as another—in other respects similar—will be eight times as heavy. But the muscular power of animals varies as the cross section of corresponding muscles, or obviously as the square of the linear dimensions; so that of two animals similarly constituted, but one twice as high as the other, the larger would be four times the more powerful. He would weigh, however, eight times as much as the other. He would therefore be only half as active. Similarly, an animal three times as high as another of similar build, would be only one-third as active; and so on for all such relations. Now, since a terrestrial man removed to Jupiter would be two and a half times as heavy as on the earth, it follows, obviously, that a man on Jupiter proportioned like our terrestrial men would be as active as they are, if his height were to theirs as one to two and a half. Hence, setting six feet as the maximum ordinary height of men on the earth, we see that the tallest and handsomest of the Jovicolæ can be but about two and a half feet in height, *if only our premisses are correct.* Thus Tom Thumb and other little fellows, if removed to Jupiter, might be wondered at for their enormous height, and eagerly sought after by any Carlylian Fredericks who may be forming grenadier corps out yonder.

One line of argument having thus led us to regard the Jovicolæ as Ogs of Bashan, while another equally plausible has reduced their dimensions to those of our

two-year-old children, we may fairly conclude that this method of reasoning is fallacious. We must not measure the inhabitants of other worlds according to the conceptions suggested by the forms of life we are acquainted with upon earth. We must admit the possibility that arrangements as different from those we are familiar with as the constitution of the insect is from that of man may be presented amid the orbs which circle round the sun. It were unwise, no doubt, to give free scope to speculation where we have, in truth, no means of forming an opinion. We need not imagine, as some have done, that 'the inhabitants of Jupiter are bat-winged,' or, with others, 'that they are inveterate dancers.' Nor, to take the views of more respectable authorities, need we agree with Sir Humphry Davy that the bodies of the Jovians are composed of 'numerous convolutions of tubes more analogous to the trunk of the elephant than anything else'; with Whewell, that they are pulpy, gelatinous creatures, living in a dismal world of water and ice with a cindery nucleus; nor finally, with Brewster, that the Jovian may have his 'home in subterranean cities warmed by central fires, or in crystal caves cooled by ocean tides, or may float with the Nereids upon the deep, or mount upon wings as eagles, or rise upon the pinions of the dove, that he may flee away and be at rest' (*sic*). So soon as we give a definite form to the conceptions that the imagination, free from the control of exact knowledge, frames respecting the inhabitants of other worlds, we touch at once on the grotesque, the

hideous, or the ridiculous.[1] It is sufficient to recognise the probability, or rather the certainty, that the beings of other worlds are very different from any we are acquainted with, without endeavouring to give shape and form to fancies that have no foundation in fact.

We may regard it as probable, however, that living creatures in Jupiter, if any exist, are built generally on a much smaller scale than those which people our earth. Trees, plants, and the vegetable world generally, must also, one would imagine, be very differently constituted from those we are familiar with. It is well known that the motion of the vegetable juices is in part regulated by the force of gravity, and therefore it must be admitted that the structure of terrestrial plants is in part dependent upon the value of gravitation at the earth's surface. Whewell, in his 'Bridgewater Treatise' on the astronomical evidence of design in creation, lays great stress on this relation, pointing out, if I remember aright, that all vegetation would be

[1] It may be worth while to gather a lesson from this circumstance. We know that every form of life is replete with evidences of adaptation (no matter how secured) to the conditions which surround it. Now man, with all his knowledge of these adaptations, so soon as he passes the boundary of the known, pictures to himself all manner of unnatural and impossible forms of existence. Even the unknown parts of our own earth have been peopled ere now, in imagination, with 'men whose heads do grow beneath their shoulders,' and other similarly incongruous beings. It is more excusable, perhaps, that an anatomically impossible structure should have been assigned to angels: (the cherubim have been even more unfortunate); while Satan, who 'goeth about as a roaring lion,' has had the principal attributes of a class of *Ruminantia* assigned to him.

destroyed at once if there could suddenly take place any marked change in the earth's attractive forces. If this view is correct, it is certain that none of our plants could thrive on the soil of Jupiter.

The year of Jupiter differs in a much more striking manner than that of Mars from our terrestrial year. It consists of nearly twelve such years as ours, so that the period corresponding to one of our seasons lasts nearly three years, and a Jovian month is nearly equal to one of our terrestrial years. He has, however, no seasons in our sense of the word, since his equator is inclined but little more than three degrees to his orbit. Thus a perpetual spring reigns all over his surface.

But before we proceed to form a high opinion of the planet's condition under the influence of this perpetual spring, let us distinctly understand what the words mean. The word 'spring' has a genial sound to ourselves, because we associate it with that which is commonly the pleasantest portion of our year; but it is just possible that the perpetual spring reigning over Jupiter, though doubtless well adapted to the wants of his inhabitants, leads to a state of things such as we might not find altogether so agreeable.

It has been said that 'as the rays of the sun fall perpendicularly on the body of the planet, and always continue to do so, the heat must be as nearly as possible equal at all times of the year, a perennial summer; this is a striking display of beneficent arrangement.' But we should be cautious in adopting this mode of argument. If Jupiter's great distance

from the sun is compensated for by this peculiar disposition of his axis, and we are to admire the beneficence thus displayed, are we therefore to find maleficence in the fact that Saturn, Uranus, and Neptune have been otherwise dealt with, though, being farther from the sun, they have greater need than Jupiter of some special arrangement of the sort? It seems safer to consider the consequences which flow from the arrangement without any special reference to its purpose, lest, in our over-anxiety to recognise beneficence in the treatment of one world, we should adopt a mode of reasoning which leads to the direct conclusion that other worlds have been ill-treated.

The great peculiarity resulting from the arrangement in question—the only peculiarity, in fact, of which we can speak with any confidence—consists in this, that everywhere on Jupiter day and night are of equal length. It is in this sense only that perpetual spring—or perpetual autumn, if we please—reigns on the giant planet. The different latitudes of Jupiter have climates differing quite as much as those found in different latitudes on our own earth. At the equator the sun passes every day nearly to the point overhead. At the poles the sun seems to glide along the horizon, rising in the east, passing round—always near the horizon—towards the south, and thence to his setting-place in the west. In intermediate latitudes the sun passes to a southerly elevation, which is greater or less according as the place is nearer to or farther from Jupiter's equator. It follows that there is a

marked difference between the sub-equatorial and the sub-polar regions in Jupiter, while between these regions every intermediate climate is to be found.

Owing to the rapidity of Jupiter's rotation, the motion of the sun in the Jovian sky must be much more readily discernible and measurable than that with which the sun seems to pass across our own heavens. He traverses the whole semicircle, from the eastern to the western horizon, in two minutes less than five hours, or about six degrees in ten minutes. This corresponds to a motion through a space equal to the sun's diameter (as we see him) in fifty seconds, and must be readily discernible, even to the unaided vision of the Jovicolæ, unless their eyesight is much inferior to ours. The smallness of the sun, as seen from Jupiter, must help to render the motion more perceptible. He presents to them an apparent diameter only equal to about one-fifth of that with which we see him, so that in ten seconds he seems to pass over a space equal to his own diameter.

The other celestial bodies are affected with similar motions as seen from Jupiter. Of course, those seen near the poles of his heavens seem relatively at rest. One of these poles lies in the heart of the constellation Draco; the other lies close by the Greater Magellanic Cloud, which must present a magnificent cynosure to the inhabitants of the southern hemisphere of the planet. The contrast between the steadfastness of the polar star-groups and the swift motions of the equatorial constellations must be impressive indeed. These

equatorial groups are no other than our old friends the zodiacal constellations. As seen by the inhabitants of Jupiter, they rise with a perceptible but stately motion above the eastern horizon, pass to their culmination on the southern meridian, and so to their setting-place in the west—exhibiting the same splendours which the terrestrial astronomer delights to gaze upon, enhanced by the peculiar impressions of active power suggested by visible and obvious motion.

It may seem, at first sight, that the presence of the Jovian satellites must tend to dim the splendour of the sidereal heavens. Our own moon, despite the beautiful passage[1] in which Homer has described the calm beauty of a moonlit night, certainly detracts largely from the magnificence of the star-groups; and as at times there must be four moons visible above the horizon of the Jovians, it might seem that all but the brighter stars would be quite obliterated. The first moon must appear somewhat larger than our own; the next has an apparent diameter rather more than half as large as that of our moon; the third (really the largest) appears about as large as the second; and the fourth has an apparent diameter equal to about a quarter of our moon's. Thus, in all, they cover a space on the sky more than half as large again as that which our moon covers. But, in reality, they cannot

[1] Homer must not be held responsible for Pope's amazing description, which, strangely enough, has found an ardent admirer in one of our best modern observers. Homer did, however, mention as a characteristic of the moonlit sky, that 'all the stars shine,' a proof that sometimes, as Horace tells us, the great master nodded.

have nearly so marked an effect in dimming the lustre of the stars. For it must not be forgotten that they shine only by reflecting the sun's light, and that he illuminates them but faintly in comparison with the light he pours upon our own moon. In effect, supposing their reflective capacities equal to the moon's, they must appear less brilliant than she does, in the proportion of about one to twenty-five; and, combining this result with the above relation, it follows that even if they could all be 'full' together, they could send to the Jovians but about one-sixteenth part of the light we receive from the full moon. But, as a matter of fact, they cannot all be full together. The motions of the inner three are so related that, though there is nothing to prevent them from being all visible together,[1] yet when so visible, one only can be full. The fourth may be full at the same time, or in fact may be associated with the other three in any way, since its motions are not bound up with theirs as theirs are *inter se*.

Even now, however, we have not reached a full estimate of the extent of the mistake which those astronomers have made who speak of the splendour with which the satellites of Jupiter illuminate his skies. When at that part of their orbits where they would otherwise be full, the three inner moons are always eclipsed; and though the fourth, by reason of

[1] Or all invisible together. Lardner asserts the contrary. One would imagine he had never seen all the moons together on the same side of Jupiter.

its great distance,[1] sometimes escapes eclipse, yet more frequently it is obscured like the others. The two inner satellites are eclipsed for upwards of two hours, and as they occupy but a few hours in completing their circuit round the sky,[2] it will be seen how largely this relation detracts from their light-supplying powers.

We see, then, that those writers have been mistaken who allege that the great distance of Jupiter from the sun is compensated by the number of his moons, and the quantity of light they reflect towards him. So far is this from being the case that, under the most favourable circumstances, they can supply during the Jovian night but about one-twentieth part of the light with which the full moon illuminates our nocturnal skies. The poetical descriptions which imaginative writers have indulged in, respecting the splendour of the scene presented by these satellites, will not bear the dry light of numerical estimation. That the satellite-system of Jupiter subserves, or may hereafter subserve, important functions need not be questioned; but that we can recognise them as created for any special purpose may be assuredly denied.

Perhaps, if one were able to discuss with advantage the special purposes which this or that portion of the

[1] Not on account of the inclination of its orbit being large, as has been asserted. The orbit of this satellite is, indeed, less inclined than the orbits of the others.

[2] Moving in a direction contrary to that due to the rotation of Jupiter, they of course remain longer above the horizon than the sun, or than the equatorial fixed stars.

universe is intended to subserve, it might be argued that the outer planets have greater need of moons than the inner, because, their year being longer, there is greater occasion for objects whose motions shall serve as measures of time. The satellites of Jupiter supply, by their separate motions, convenient measures of the shorter time intervals; while, by their successive conjunctions, (i.) in pairs, (ii.) the three inner together, and (iii.) the outer with pairs of the inner, they afford convenient measures of longer intervals.

But let us turn from vague guesses such as these to the consideration of those facts which are actually presented to our notice.

Recognising the existence of varied climatic relations in different parts of Jupiter, we have now to consider the climate of the planet generally, to contemplate the position of this great orb in the solar system, and to determine how far its great distance from the sun may be compensated by other relations.

There can be no doubt that the amount of heat poured by the sun on any portion of Jupiter's surface placed perpendicularly with respect to the heat-rays, must be very much less than the amount received by an equal portion of our earth's surface similarly situated. The direct heating effects of the sun must in fact, as already stated, be less on Jupiter than on our own earth, in the proportion of about one to twenty-five. And it cannot be doubted that the effects of this difference must be highly important, whatever circumstances may compensate for the de-

ficiency of heat. If we can demonstrate in any way that the mean temperature of the Jovian atmosphere is equal to that of our own air, or even greater, yet the difference of the sun's direct heat involves a variety of consequences which we cannot disregard.

We know, for instance, that it is principally the direct heat of the sun that causes the evaporation of water from the surface of oceans, seas, lakes, and rivers, and therefore all the important consequences which flow from the presence of aqueous vapour in large quantities in the earth's atmosphere. We can conceive the existence of vapours in the air which might keep away from the earth's surface the greater portion of the sun's heat, and yet, preventing the escape of the remainder by radiation into space, might leave the general warmth of the air around us as great as it is at present. But it cannot be doubted that such an arrangement would injuriously affect the whole economy of evaporation and its consequences, winds, rains, clouds, mist, with *their* consequences, so important to terrestrial races.

And in like manner other effects accruing from the direct action of the solar rays might be considered.

It follows, then, that it is by no means sufficient to show how the heat which falls upon Jupiter may be stored up, through the action of some component of his atmosphere in preventing its radiation into space. It is, indeed, of the utmost importance to know that even this is possible, because we are thus enabled to see that Jupiter is not necessarily an abode so bleak

and desolate as some writers have imagined. In the following passage, Professor Tyndall has exhibited the means by which this result may be brought about, and the inhabitants of the noblest planet in the solar system placed somewhat higher in the scale of creation than Whewell surmised. 'In these calculations,' he remarked, referring to Whewell's estimate of the sun's heating power on Jupiter and the other exterior planets, 'the influence of an atmospheric envelope was overlooked, and this omission vitiated the entire argument. It is perfectly possible to find an atmosphere which would act the part of a *barb* to the solar rays, permitting their entrance towards the planet, but preventing their withdrawal. For example, a layer of air, two inches in thickness, and saturated with the vapour of sulphuric ether, would offer very little resistance to the passage of the ether rays, but I find that it would cut off fully thirty-five per cent. of the planetary radiation. It would require no inordinate thickening of the layer of vapour to double this absorption; and it is perfectly evident that with a protecting envelope of this kind, permitting the heat to enter but preventing its escape, a comfortable temperature might be obtained on the surface of our most distant planet.' The difference between such an arrangement as this and the way in which the earth's temperature is obtained is the exact converse of that dealt with when we were considering the case of Mercury and Venus. Precisely as the mean temperature of the atmosphere of either of the interior

planets may be no higher than that of our own air, while yet the sun's direct rays continue wholly unbearable, so the outer planets may have a perfectly comfortable temperature, while yet that direct solar heat which exerts so many important influences on the earth must be supplied only in quantities which we should find wholly inadequate for our wants.

I am far from desiring to infer that Jupiter may not hereafter be uninhabited, or even that creatures then existing on his surface must necessarily differ wholly in their nature from any with which we are familiar. But I think that while, on the one hand, we must reject one of the chief arguments by which Whewell was led to people Jupiter with cartilaginous and glutinous creatures floating in boundless oceans, so, on the other, we cannot accept without question the argument by which an effort has been made to indicate the possibility of a close correspondence between Jupiter's climate and our earth's.

And here we are led to the most interesting and suggestive of all the relations exhibited by Jupiter, or rather to three closely associated relations which lead to views of a somewhat startling character.

In common with the other large planets lying outside the zone of the asteroids, Jupiter has a mean density falling very far short of the mean density of the earth or the other small planets which travel within that zone. According to the best estimates of his mass and apparent diameter, his mean density would seem to be rather less than one-fourth of the

earth's, or greater than the density of water by about one-third. It is worthy of remark, in fact, that his density is almost exactly the same as the sun's, and considerably greater than that of the other three outer planets hitherto discovered.

If we were quite certain that the disc measured by us exhibits the real outline of the planet, or that his atmosphere is not of abnormal extent, and that his globe is solid throughout, it would follow that the substances composing Jupiter are either altogether different from those forming our earth, or that they are combined in very different proportions. On the last point we can form no opinion. On the first we must be guided by the appearance of the planet.

Thus we are led to the second of the three relations just mentioned—the appearance of well-marked but variable belts on the planets, and of other indications implying the existence of an atmosphere of great depth.

The belts of Jupiter are commonly arranged with a certain symmetry on either side of the great equatorial bright belt, but sometimes there is a rather marked contrast between the northern and southern halves of the planet. In colour the dark belts are usually—when seen with suitable telescopic power[1]—of a cop-

[1] What is required is not so much a high light-gathering as a high magnifying power, though both points are of importance. When the light is not adequately reduced by increase of magnifying power, the colour is lost in the resulting 'glare.' Reflectors seem to have an advantage over refractors in exhibiting the colours of the planets; at least, nearly all the accounts in which the ap-

pery, ruddy, or even purplish tint, while the intermediate light bands vary from a pearly white in the equatorial belt, through yellowish-white in the middle latitudes of both hemispheres, to a greyish or even bluish tint at the poles. The picture of Jupiter which forms the frontispiece, while exhibiting many of the features usually seen, is intended specially to illustrate relations presently to be dealt with.

There is every reason to believe that these belts indicate the existence of a very extensive vapour-laden atmosphere. The dark belts must not be considered as the true cloud-belts, because it must be remembered that we look upon the reverse side of the skyscape presented during the day to the Jovians: so that where they see densely compacted dark clouds, we see the light which those clouds have intercepted; and, on the other hand, where they see clear spaces, the light which reaches them is not reflected to us without a considerable loss of brilliancy. Thus the dark belts of Jupiter are those regions where—if at all—we see the true surface of the planet.

Now, viewing the belts in this light, have we any means of judging from their aspect what is the extent of the planet's atmosphere? So far as I know, the question has never been considered, but it is well worthy of careful study.

It seems clear, in the first place, that if the bright belts really are cloud-belts, and the dark belts the surface

pearance of colour has been specially dwelt upon have been received from observers who have used reflectors.

of the planet, then on the edge of the planet's disc we ought to see some irregularity of level—the cloud-belts projecting slightly beyond the real outline of the planet —if the atmosphere have that enormous extent which some astronomers have supposed. Whether such an appearance has ever been looked for I do not know, but it has certainly never yet been detected.

We are led to conclude, then, that either the atmosphere of Jupiter is not sufficiently extensive to interfere appreciably with our measurement of the planet's bulk, or else the dark belts belong but to a lower cloud-layer, not to the planet's real surface.

We have further evidence on this point in the appearance of dark spots on the dusky belts. These spots have ever been described as black, though surely their appearing of that hue must be ascribed to the effect of contrast. Now these dark spots, which have been seen by Cassini, Mädler, Schwabe, and others, may be regarded as the real surface of the planet (unless they belong to a yet deeper cloud-layer), seen for a while through openings in the cloud-bed to which the dusky belts belong. The reader will not fail to notice here some resemblance to what has been already mentioned respecting the sun-spots; and when we come to the third and most striking of the associated features I am now dealing with, it will be seen that there may be more in the analogy than one might at first sight be disposed to imagine.

How far the appearance of small round white spots on the dark belts may be considered as indicative of

the extent and constitution of the Jovian atmosphere, it is not very easy to determine. That they are dense clouds, hanging suspended above the dusky cloud-layer, must be admitted as highly probable, but it is open to question whether they have formed there in the same way that cirrus clouds are seen to form at a great elevation above a layer of cumulus clouds, or whether they indicate the action of volcanoes beneath the dusky layer, propelling enormous streams of vapour through the superincumbent cloud-beds.

The third point on which I have to dwell is the variability of the belt-system, under which head I include not only variations in shape and extent, but those much more significant changes of colour which have been recently discovered.

So far as is yet known, there is no recognisable law in the changes of shape exhibited by the belts of Jupiter —no periodicity or intelligible sequence. It may be suggested, in passing, that a systematic and persistent scrutiny of the planet might lead to the discovery of laws of this sort, which could not fail to indicate physical conclusions of the utmost importance. Nay, further, since we cannot doubt that the condition of the real surface of Jupiter is in some sort reflected, so to speak, in the aspect of his cloud-envelopes, it seems far from unlikely that a scrutiny of this sort might tell us where his oceans and continents, where his deserts, lakes, or rivers, are situated, even though no direct evidence of their existence might ever reward the observer. In these days, however, nine-tenths of

those who are fortunate enough to possess fine telescopes prefer either to leave them idle, or to employ their powers in making observations, at great pains and labour, which are not worth the paper on which they are recorded. The few original observers we have are overtasked by the multitude of questions of interest presented to their consideration; so that many subjects of inquiry must perforce wait, either till their turn arrives, or till those who have the means of studying them choose to turn their thoughts from the sterile subjects they are now engaged upon.

So far, then, as inquiries have as yet been pushed, all that can be asserted on the subject we are considering is, that the planet's belts vary greatly in form, extent, and general appearance. At one time the dusky belts cover a large proportion of the planet's disc, at another they are singularly narrow. Now they are very regularly disposed, now they seem in some way under the action of disturbing forces of great intensity, causing them to assume the most irregular figure. The accompanying picture of the planet (fig. 1), as seen by Mr. Browning with one of his own reflectors, indicates an appearance not uncommonly seen, a dark streak extending obliquely across the planet's equatorial regions. The number of belts is singularly variable. Sometimes only one has been seen, at others there have been as many as five or six on each side of the planet's equator. In the course of a single hour Cassini saw a complete new belt form on the planet; and on December 13, 1690, two well-marked belts vanished

completely, while a third had almost disappeared in the same short interval of time.

The storm-tossed aspect of the planet is well shown in the characteristic drawing by Mr. De la Rue, which forms the frontispiece.

But if we seem to recognise here the action of forces much more intense than those which influence the con-

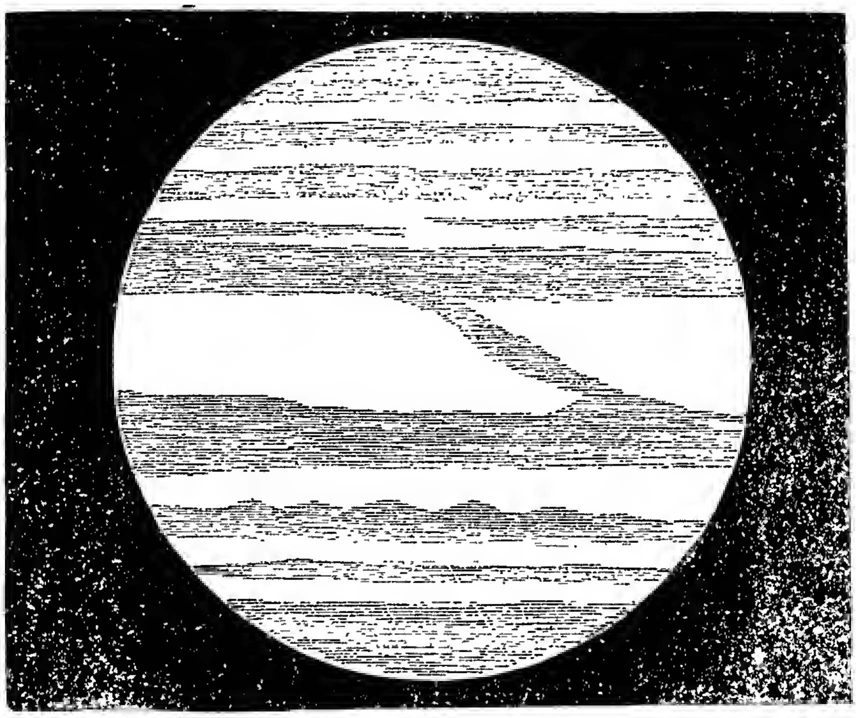


Fig. 1. The Planet Jupiter (Browning).

ditions of the earth's atmosphere, we have still more striking evidence to the same purpose in the changes of colour which have recently been detected in the great equatorial belt. This belt is usually of a pearly white tint, and has long been recognised as one of the most constant features of the planet's aspect. As the mean surface of this belt cannot be less than a fifth of the whole surface of the planet, it is clear that any

changes which may take place in its general aspect cannot but be of the utmost significance. Now, during the autumn of 1869 and the spring of 1870, this belt was more strongly coloured than any part of the planet. Mr. Browning, observing Jupiter in the earlier part of the above-named interval, found the equatorial belt of a greenish-yellow colour, which deepened in October 1869 to a full ochreish yellow, and in January 1870 had assumed an even darker tint, resembling yellow ochre. On one occasion, and on one only, he detected this tint in the first bright belt north of the equator. While thus exhibiting strongly marked and changing colours, the equatorial belt had lost its right to be called, *par excellence*, the bright belt of the planet, being considerably inferior in brilliancy to the narrow bright belts north and south of it.

Other observers have also seen these colours. Mr. Slack, with a 6-inch Browning-With reflector, and Mr. Brindley, with an 8½-inch telescope of the same construction, have witnessed most of the changes of colour above described; and I myself, using Mr. Browning's 12¼-inch telescope, found the greenish-yellow tint of the equatorial belt in the autumn of 1869 altogether unmistakable.

In the phenomena here described we have a problem whose interpretation is far from easy. Changes in the shape, disposition, and extent of the dark belts are sufficiently intelligible when we associate them, as we seem justified in doing, with variations in the position of the currents which traverse the vaporous envelope

of Jupiter as the trades and counter-trades traverse the earth's atmosphere. But the equatorial zone is Jupiter's belt of calms, resembling in this respect the equatorial region, called by sailors the 'doldrums'; and though occasional storms might be expected to agitate this region, yet processes of change continuing for several months in succession can evidently not be attributed to any such cause. We are taught by the progress of recent research to regard the colour of the light derived from any source as a relation of the most instructive character; and changes of colour, especially changes affecting so enormous a body as Jupiter, and so extensive a proportion of his surface, cannot but be looked upon as highly significant. Supposing we regard the ordinarily white light of the equatorial belt as indicative of the existence of enormous masses of cloud, reflecting ordinary solar light to us, then we should have to regard the appearance of any other colour over this region as an indication that these cloud-masses had been, through some unknown cause, either wholly or in part swept away. But—passing over the objection that this view leaves our difficulty unexplained—even if we assumed that in this way a portion of the surface of Jupiter had been brought into view, wholly or partially, why should this surface not exhibit a constant appearance? We cannot suppose changes affecting Jupiter's real surface are taking place with sufficient rapidity to explain the series of strange colour-changes observed by Messrs. Browning, Slack, and other astronomers. But if, on the

other hand, we assume that a portion of the light ordinarily received from the bright belt is inherent—that is, that the planet is, to some extent, self-luminous, then there remains the difficulty of explaining by what conceivable processes the equatorial regions are filled with a yellow light, so full and bright as to reach our earth from beyond four hundred millions of miles.

But I have spoken of the three relations last considered—the small density of Jupiter, his extensive atmosphere, and the changes which take place in the shape and colour of his belts—as associated phenomena. It remains that I should endeavour to justify this statement.

We know that Whewell, reasoning from the low specific gravity of Jupiter, was led to the conclusion that either the substance of the planet is wholly watery or else a few cinders in the centre of Jupiter's globe constitute the only solid portion of his substance. It need hardly be said that the whole progress of modern astronomy is opposed to this view. We have seen that in the sun the same elements exist as in the earth; and in Mars, the only planet whose nature we have been able to examine satisfactorily, we find evidence of the existence of the same forms of matter that we see around us. It cannot but be held as highly improbable that the earth is the only member of the planetary system whose substance thus closely resembles that of the parent orb; nor is it likely that Mars is the only planet whose general atmospheric constitution resembles the earth's. Far more probably the lesson we

are really to learn from these circumstances, is that throughout the solar system a general similarity of constitution exists, the sun being, so to speak, the type of the family over which he rules. Differences of *condition* we are compelled to recognise, since the sun itself, though constituted of the same elements as the earth, is in so different a state, and has a mean density relatively so small; but we have no evidence justifying us in believing that any important differences of constitution exist throughout the solar system.

Thus we are led to regard the singularly small density of Jupiter, and of the other planets outside the orbits of the asteroids, as due rather to some peculiarity in the condition of these orbs than to any such peculiarity of structure as Whewell insisted on. It will be seen at once that Jupiter's extensive atmospheric envelope, and the strange changes in the aspect of his belts, are circumstances which tend strikingly to confirm this impression. Let it be remembered that, supposing Jupiter's globe even to be wholly covered with water, yet a sun twenty-five times further off than ours could not by any possibility load the planet's atmosphere with the enormous masses of vapour actually present in it. Let it be remembered, further, that the relatively sluggish action of the sun upon Jupiter could not by any possibility give rise to atmospheric disturbances so tremendous as those which are indicated by the rapid changes of figure of his cloud-bands.[1] When to this

[1] It is worthy of consideration, also, that even though the sun acted as efficiently upon the air and oceans of Jupiter (assumed to

we add the relative minuteness of the seasonal changes on Jupiter, we see at once that unless some other cause than solar action were at work, Jupiter's atmosphere ought to be very much calmer than the earth's.

There is yet another circumstance in the condition of Jupiter's belts which opposes itself in a very striking (I might even say altogether convincing) manner against the belief that the belts of Jupiter are raised by the sun's action. The tropical cloud-zone of the earth not only varies in position with the seasons—passing considerably to the north of the equator in summer, and considerably to the south in winter, but it is in truth a region of midday cloudiness, not of general cloudiness. As respects the former relation we can learn little from Jupiter's aspect, because his inclination is so small that the annual sway of his equatorial zone would be exceedingly small also, and might well remain undetected. But as the belts of Saturn must be regarded as well as those of Jupiter in forming an opinion on the subject we are upon, and as the chief bright belt of Saturn, despite the considerable

be similar to our own), yet atmospheric disturbances (due chiefly, as we know, to these two forms, of action) could not possibly be so violent even as on our own earth, since corresponding latitudes on Jupiter (that is, regions where corresponding effects would be experienced) are separated by distances so very much greater. It is clear that if along a certain zone of a planet the sun exerts a certain amount of influence, while along another he exerts a different influence, the result of the difference, looked on as a cause of atmospheric disturbance, must be smaller as the distance between the zones is greater.

inclination of the planet's equator, remains throughout the year persistently equatorial, we may conclude that the Saturnian belts—and presumably, therefore, those of Jupiter also—are not sun-raised. To suppose that the sun would have power to raise belts of clouds, and yet that he would not have power to cause them to follow him as he passes far to the north and to the south of the Saturnian equator in the long Saturnian year of twenty-nine terrestrial years, seems unreasonable in the extreme. It is, however, from the second relation that the most direct argument is derived in the case of Jupiter. In the latitude of the terrestrial cloud-zone the sun rises in a clear sky; shortly before noon the sky has become overcast, and storms of rain and thunder continue until the afternoon is well advanced, after which the clouds pass away and the sun sets—as he had risen—in a clear sky. Now we know quite certainly that nothing of this sort happens in the case of Jupiter; for we see his equatorial bright belt stretching right athwart his disc;—that is, not only covering the centre of the disc, where it is noon on the planet, but extending to the edge on either side, or to places where the sun is rising and setting. There seems no escape from the conclusion that the belt is wholly different in character from our terrestrial cloud-belt—that, in fact, it is not sun-raised at all.

It seems to me that these considerations point with tolerable clearness to the conclusion that, within the orb which presents so glorious an aspect upon our skies, processes of disturbance must be at work wholly

different from any taking place on our own earth. That enormous atmospheric envelope is loaded with vaporous masses by some influence exerted from beneath its level. Those disturbances which take place so frequently and so rapidly are signs of the action of forces enormously exceeding those which the sun can by any possibility exert upon so distant a globe. And if analogy is to be our guide, and we are to judge of the condition of Jupiter according to what we know or guess of the past condition of the earth and the present condition of the sun, we seem led to the conclusion that Jupiter is still a glowing mass, fluid probably throughout, still bubbling and seething with the intensity of the primæval fires, sending up continually enormous masses of cloud to be gathered into bands under the influence of the swift rotation of the giant planet. No otherwise, as it seems to me, can one explain the intense vitality, if I may use the expression, of a planet circumstanced as Jupiter is. No otherwise can one understand whence his atmosphere is loaded with vapour-masses whose contents must exceed, on a moderate computation, all the oceans on the surface of this earth. When we see masses so enormous swayed by influences of such energy that intermediate belts thousands of miles in width are closed up in a single hour,[1] when we recog-

[1] Even if we take the disappearance of a dark belt to be due to the formation of clouds, which is perhaps more probable than that the clouds of neighbouring belts have *closed in*, the forces represented by the change are nevertheless tremendous.

nise the tremendous character of the motions which from beyond four hundred millions of miles are distinctly cognisable by our telescopes, we see that we have no ordinary phenomena to deal with, and that the theory we adopt for their explanation cannot be otherwise than striking and surprising.

If the view which I have here put forward—or rather, the view to which I have been led by a careful consideration of the phenomena which Jupiter presents to our contemplation—be indeed correct, we must of course dismiss the idea that the giant planet is at present a fit abode for living creatures. Yet need we not turn from his system with the thought that here at least our hopes of recognising other worlds have been disappointed. If Jupiter be still in a sense a sun, not indeed resplendent like the great centre of the planetary scheme, but still a source of heat, is there not excellent reason for believing that the system which circles around him consists of four worlds where life—even such forms of life as we are familiar with—may still exist? Those four orbs, which our telescopes reveal to us as tiny points of light, are in reality globes which may be compared with the four worlds that circle nearest to the sun. I have shown that they cannot subserve the purpose which many astronomers have ascribed to them, of compensating Jupiter for the small amount of light he receives, even if they could be seen from any point of his cloud-encompassed surface. So that, even adopting the commonplace and superficial view that the purpose of any object may be regarded as ascertained

when we have been able to ask (without any obvious answer) what other purpose it *can* subserve, we still are led to the belief that the satellites of Jupiter must be the abode of life, since on this view, and on this view only, we find a *raison d'être* both for the planet and for the system which circles round him.

There are no considerations which appear directly opposed to the view that Jupiter is in a sense a sun. It need hardly be said that I do not regard him as being in the same condition as the central luminary of the planetary system. If he is an incandescent body, the greater part of his light is veiled by the cloud-envelopes which surround him. The solar clouds are, as we know, themselves luminous; those of Jupiter are not so—a circumstance which indicates that the heat of Jupiter is not sufficient to vaporise those substances which are incandescent when in the liquid state. The outer layer of clouds must, therefore, be regarded as for the most part aqueous. We see *there*, in fact, the future oceans of Jupiter, if the hypothesis I am now dealing with be correct.

That Jupiter may supply an immense amount of heat to his satellites (on this view of his condition) is perfectly clear, since the amount of light he emits is no adequate measure of the amount of obscure heat which radiates from him to the four worlds around him. When we consider the enormous apparent size of Jupiter as seen from his satellites, we recognise at once how large a supply of heat he is capable of trans-

mitting to them. From the outermost satellite his apparent diameter exceeds that of the sun (as seen by us) some eightfold, and his apparent size, therefore, exceeds the sun's more than sixty-fold. From the innermost he is seen with a diameter nearly forty times that of the sun, and with an apparent area more than 1,400 times as large as his!

We have evidence, however, which renders it far from improbable that Jupiter may emit some small proportion of light. I have already referred to the singular excess of his brilliancy over that due to his size and his distance from the sun and from us. The estimates of Zöllner, the eminent photometrician, serve to show, not indeed that Jupiter sends more light to us than he receives from the sun, but that he sends much more light than a planet of equal size, and, constituted like Mars, the moon, or the earth, could possibly reflect to us if placed where Jupiter is. Whereas Mars reflects but one-fourth of the light he receives, Jupiter reflects more than three-fifths. The moon sends less than a fifth; Saturn, Jupiter's brother giant, more than a half. The late Professor G. Bond, of America, actually calculated that Jupiter sends forth more light than he receives. Whether his observations or the more systematic observations of the German astronomer are accepted, we see that unless we adopt some such hypothesis as I have dealt with above, we must recognise a marked difference between the relative light-reflecting capacities of the two largest planets of the system, and those of Mars or the moon. In

fact, from other researches of Dr. Zöllner's, it follows that if Jupiter does not shine in part by native light, his surface must possess reflective powers nearly equal to those of white paper. Now this would scarcely be credible, even though under the telescope the planet's surface were found to be uniformly white; but as we find a large proportion of it to be of a dull coppery hue, we seem forced to admit that it cannot really have an average reflective power nearly so great as that calculated by Zöllner. It follows, as at least highly probable, that Jupiter shines in part by his own light; and this being admitted, we cannot but regard it as highly probable that the real globe of the planet must be intensely hot.

It may seem, at first sight, that the apparent blackness of the satellites' shadows, as seen on the disc of Jupiter, is wholly opposed to the view that any portion of his light is native. But as a matter of fact there is no force at all in this consideration, or rather, whatever weight we may attach to the observed appearance of the satellites' shadows is in favour of the strange theory here put forward. For it has been a subject of remark among the most experienced observers, that a satellite in transit will occasionally appear as dark as its shadow, both seeming black. The blackness, then, is only apparent, and an effect of contrast. In reality, if such observations as I have mentioned are to be trusted (and I know no reason for disregarding them), the shadow of a satellite is not black, and therefore there seems no escape from the conclusion that the

surface on which they are projected is partially self-luminous.

A stronger argument against the belief that Jupiter is self-luminous lies in the fact that the satellites disappear in his shadow. It must be remembered, however, that in any case we can assign but a small proportion of inherent light to Jupiter, and that his satellites would therefore, in any case, lose so large a proportion of their light when passing into his shadow that we might expect them to disappear, even under the closest telescopic scrutiny.

One of the most surprising phenomena ever witnessed by the telescopist seems to me to afford even stronger evidence than any yet adduced. I refer to the observation made by Admiral Smyth, that on one occasion the second satellite of Jupiter, twelve minutes after entering on the disc of the planet, was seen *outside the limb*, 'where it remained four minutes, and then suddenly vanished.' Two other equally competent observers, Maclear and Pearson, witnessed the same phenomenon. 'Here,' says Webb, 'explanation is set at defiance.' But it is precisely where explanation seems set at defiance that we have reason to be most hopeful of gaining instruction. The observation is very startling, it is true; and the explanation may be expected to be also surprising. But I think it is not far to seek. The satellite cannot have retraced its course; Jupiter cannot have shifted his place; our atmosphere cannot be in question: all these explanations being eliminated, our task is rendered easier

instead of more difficult. A change in Jupiter's cloud-laden atmosphere, corresponding to that which I shall presently have to exhibit as explaining Saturn's occasional assumption of the square-shouldered aspect, will obviously account for the phenomenon. It is well known that the acute observer Schröter occasionally suspected an apparent flattening of portions of Jupiter's outline, but the suspicion had been regarded as erroneous. We find, however, in the observation now in question, effective confirmation of that long-doubted observation of Schröter's. If we consider the matter rightly, this observation, made simultaneously by Smyth, Maclear, and Pearson, renders that view all but certain which hitherto I have presented only as a highly probable hypothesis.

Although I have already far exceeded the limits I had proposed to myself for the consideration of this noble planet, it is with regret that I take leave of him to pass onward to the outermost bounds of the solar system. I would fain dwell even longer than I have on a subject of contemplation at once so interesting and so instructive. Jupiter, the centre of a noble system of worlds, or Jupiter, himself a world inhabited by beings as high perhaps in the scale of creation as he himself is in the scheme of the planets, is alike a worthy subject of study. The more one dwells on the features he presents, the more one is impressed with the sense of the grandeur of his position in the universe. One who has not gazed hour after hour on the glories of the giant planet, gathering fresh delight as feature

after feature is revealed beneath his scrutiny, may disregard the grand lesson which the heavens are always teaching. But the astronomer, imbued with the sense of beauty and perfection which each fresh hour of world-study instils more deeply into his soul, reads a nobler lesson in the skies. The music which reaches his ears may be fitful, but it is not 'as sweet bells jangled out of tune and harsh'; he may not master its full meaning, though every note thrill through his inmost soul; but even when its sounds are least distinct, they are full of mystical solemnity. In fine, the true astronomer may say with the Pythagorean, though in another sense,—

> There's not one orb which thou behold'st
> But in his motion like an angel sings,
> Still quiring to the young-eyed cherubim;
> But while this muddy vesture of decay
> Doth grossly close us in, we cannot hear it.

CHAPTER VI.

SATURN, THE RINGED WORLD.

If Jupiter by his commanding proportions affords a forcible argument against the view that our tiny earth is the only real world in the solar system, Saturn supplies an argument of scarcely inferior strength in the singularly complex character of the scheme of which he is the centre. No one can contemplate this glorious planet, as shown by a telescope of adequate power, without being impressed by the conviction that he is looking at a world altogether more important in the scheme of creation than the globe on which we live. Whether he recognises in the present condition of the planet the result of the action of laws which have for vast periods reigned through the universe, or whether he prefers the view that Saturn and his system are seen now as they were fashioned at the beginning by an Almighty creative hand, he is alike amazed at the complexity of structure exhibited in the scene on which he is gazing. He may not be able, indeed, to appreciate the true character of the life work which the various parts of the Saturnian system are doing, or he may, in a too hasty attempt to solve the mighty

problem, be led to erroneous conceptions; but that the great planet speaks of life, past, present, or to come, he cannot gravely question.[1]

In volume and mass Saturn is inferior to Jupiter. Jupiter is 1,230 times, Saturn not quite 700 times, as large as the earth; and while Jupiter outweighs her 300 times, Saturn is scarcely 90 times as heavy as she is. Still Saturn is sufficiently large and massive to dwarf our earth to insignificance; and even Uranus and Neptune, though belonging to the family of the major planets, and giants compared with the earth, fall below Saturn far more than he does below Jupiter.

Like Jupiter, Saturn rotates very rapidly on his axis, the length of his day being about $10\frac{1}{2}$ of our hours. The materials of which Saturn is composed have a mean density not much greater than half that of Jupiter, or less than three-fourths of the mean density of water. In fact, Saturn's mean density is specifically less than that of any known planet. It seems not impossible that we have in this relation some indication of the true cause of that complexity of detail which the Saturnian system exhibits.

The equator of Saturn is inclined about $28\frac{1}{5}$ degrees to the plane in which the planet moves, so that his seasons (so far as they depend on this circumstance)

[1] I know nothing better calculated to lead men to choose astronomy as their favourite subject of study than the contemplation of the Saturnian system. I can well remember the sensations with which I saw the ringed planet for the first time. I look on that view as my introduction to the most fascinating of all the sciences

closely resemble in character those of the planet Mars. He occupies about $29\frac{1}{2}$ years in circling once round the sun; this, therefore, is the length of the Saturnian year. His distance from the sun is nearly twice that of Jupiter, and nearly ten times that of the earth; so that the amount of light and heat which any portion of his surface receives from the sun is about $\frac{1}{91}$ part of that received by a similar portion of the earth's surface. His orbit being somewhat eccentric, however, there is a considerable variation in this respect during the course of a Saturnian year, insomuch that when he is nearest to the sun he receives more light than when in aphelion, in the proportion of about 5 to 4.

Most of the relations which have to be considered in discussing the habitability of Saturn have been already dealt with (under very similar conditions) in treating of other planets; so that I propose to touch on them very lightly, in order to come more quickly to those circumstances which distinguish Saturn specially among the other members of the solar system.

Gravity at his equator is almost exactly equal to gravity at the earth's surface. Near the poles there is a marked increase in the action of Saturnian gravity, insomuch that a body weighing 10 pounds at his equator would weigh about 12 pounds at either pole. There is nothing, however, in this peculiarity which need be specially dwelt upon.

The length of the Saturnian year, and the small quantity of light and heat received from the sun, are simply more marked instances of what has already

been considered in the case of Jupiter. We may conclude with some confidence that these relations are quite sufficient to render Saturn wholly uninhabitable by such creatures as exist upon the earth; but there seems no reason for supposing that (so far as these relations alone are concerned) the planet may not be the abode of living beings as high in the scale of creation as any which live upon our globe.

Thus viewing Saturn, we cannot regard even the exceptional effects produced by his ring-system as of themselves sufficient to banish life from his surface. These effects are not without interest, however, and as they have been made the subject of some discussion, I think it well to make a few remarks upon them.

I apprehend that when Sir John Herschel said that the rings occasion an eclipse of nearly fifteen years in duration, first to the northern and then to the southern hemisphere of the planet, he meant simply that during an interval of such length a large portion of either hemisphere was in shadow. He knew perfectly well that long after the edge of the ring has been turned directly towards the sun, a very large proportion of the hemisphere over which the ring's shadow proceeds to sweep remains illuminated. It had always seemed to me, therefore, altogether a mistake on the part of Dr. Lardner to interpret Herschel's words as though implying that a whole hemisphere of the planet is eclipsed for fifteen years in succession.

So misinterpreting the expression used by Sir John

Herschel, Dr. Lardner, in his desire to show that no such relation existed, was led into real mistakes such as a sounder mathematician would not have made. He examined the relations presented by the ring in a *quasi*-mathematical but inexact manner, and came to the following conclusion—'that by the apparent motions of the heavens produced by the diurnal rotation of Saturn, the celestial objects, including the sun and the eight satellites, are not carried parallel to the edges of the rings; that they are moved so as to pass alternately from side to side of these edges; that, in general, such objects as pass under the rings are only occulted by them for short intervals before and after their meridional culmination; that although, under some rare and exceptional circumstances and conditions, certain objects—the sun being among the number—are occulted from rising to setting, the endurance of these phenomena is not such as has been supposed, and the places of their occurrence are far more limited.' All these statements are more or less incorrect, and most of them are the direct reverse of the truth. The seven inner satellites of Saturn stand in an altogether different relation with respect to the rings from all other celestial objects, since they travel in the same plane and in circles concentric with the outlines of the rings: they can no more be occulted by the rings, therefore, than an outer ring can be occulted by an inner one. So far is it, again, from being true that the sun is in general only occulted for a short time before and after culmination, that the

more common case (considering the whole planet) is for the sun to be eclipsed (if at all) throughout the whole of the Saturnian day; and a very common case, left altogether unnoticed by Dr. Lardner, is that the sun is occulted in the forenoon and afternoon, but free from eclipse in the middle of the day. Nor is it true that the places where the sun can be totally eclipsed throughout the day are limited to a relatively small portion of the planet, since every part of the planet whence the rings are visible at all has the sun eclipsed by the rings throughout the whole day for a longer or shorter succession of rotations. In the remaining or polar regions of the planet the sun is altogether absent for long intervals of time, for the same reason that he is absent from the skies of our polar regions during a comparatively short interval. As for the endurance of the total diurnal eclipses, it is only necessary to remark that in the Saturnian latitude corresponding to that of London or Paris the sun is totally eclipsed for more than five years in succession, while in the latitude corresponding to that of Madrid he is totally eclipsed for nearly seven years in succession. This suffices to show that an arrangement which the inhabitants of earth would find wholly unendurable prevails over a very large proportion of Saturn's surface.[1]

[1] The views here expressed as to the effects of the Saturnian rings are founded on exact mathematical calculation, of which the elements are given in my treatise on Saturn. The problem is not by any means a difficult one, and the only way in which the erroneous views formed by Dr. Lardner can be explained is by considering that he dealt with the problem in a general instead of an

But if we consider the matter rightly, we shall see that this, after all, need not surprise us, since there is already in the enormous distance of Saturn from the sun the amplest reason for believing that he cannot be inhabited by such creatures as exist upon the earth. It is in vain that by conceiving him to be surrounded by a dense atmosphere we assign to him a mean climate as warm as that of the earth. The want of direct solar heat still remains, and must be regarded as a fatal objection to the habitability of Saturn by races resembling those with which we are familiar.

In the case of Saturn as in the case of Jupiter, the provision of satellites and of the rings which form so glorious an object to the astronomer on earth is altogether inadequate to increase the supply of light received by the Saturnians to any such extent as has been imagined. Those well-meaning persons who insist on their own interpretation of Deity's designs are singularly successful in overlooking very obvious difficulties. If the design of the rings, for instance, really were to compensate the Saturnians for the small amount of light which they receive from the sun, it would surely follow that there was a want of wisdom in the selection of an arrangement by which more light is kept away from Saturn than the rings can possibly

exact manner. I could not feel any doubt as to the accuracy of my results, but I was not the less pleased to receive a letter from Mr. Freeman, a fellow of St. John's College, Cambridge, stating that he had obtained similar results, and had constructed a table on the plan of Table XI. in my 'Saturn,' and so closely according with it as not to need separate publication.

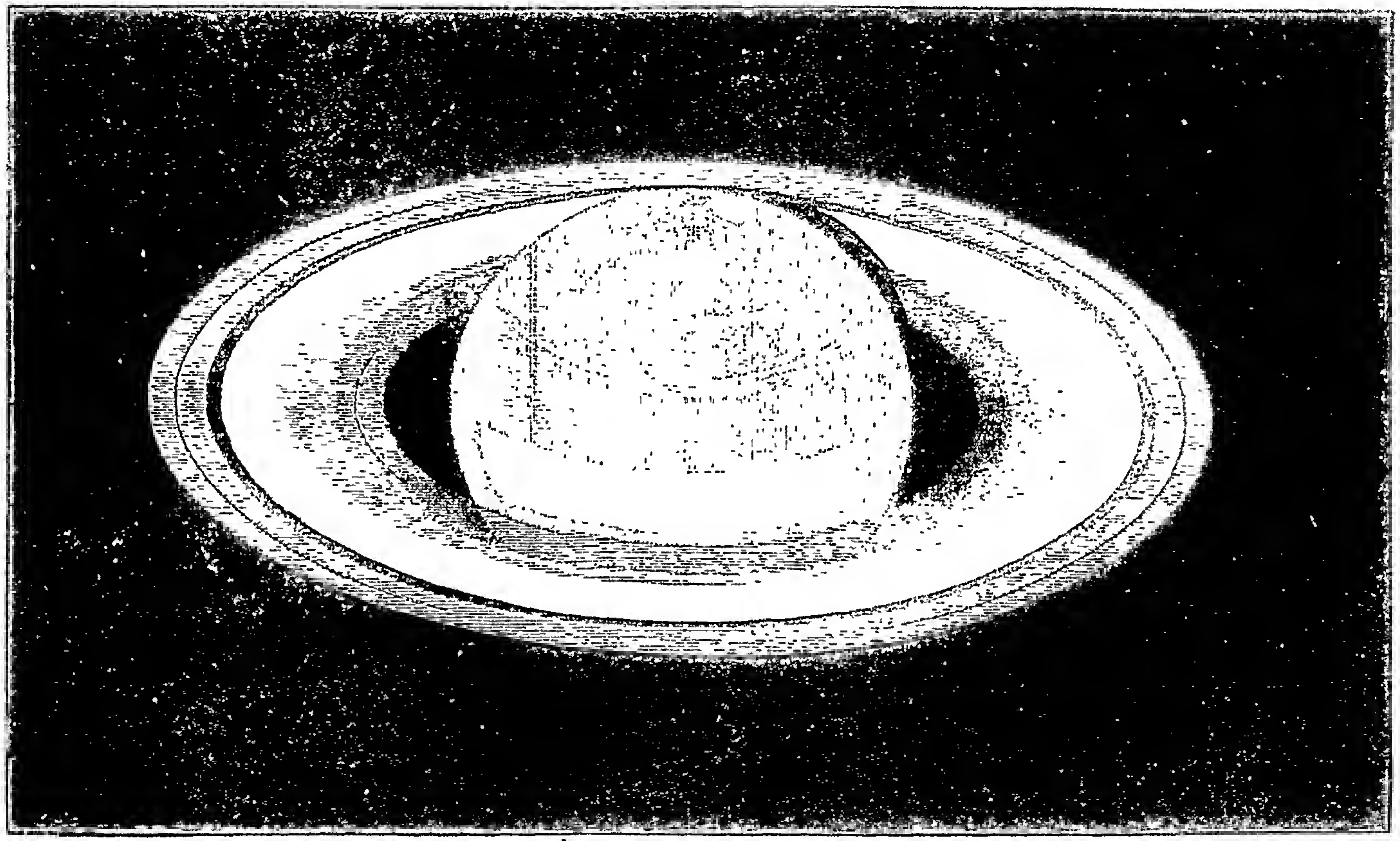
reflect to him. And, further, during the very season when the extra light derived from the rings is most required by the planet, that is, during the long nights of the Saturnian winter, they exhibit a dark band upon the heavens, concealing whole constellations from the view of the Saturnian people. As far as the satellites are concerned there is no corresponding difficulty. They undoubtedly reflect the sun's light to Saturn, and if there really are intelligent beings on the planet, the satellites must undoubtedly present an interesting spectacle, especially when a large number of the moons are nearly full. But a little consideration will show that even though all the satellites were full at the same time, the quantity of light they could send back to their primary would be wholly inadequate to compensate for the planet's great distance from the sun. According to the best estimates of their magnitude, the eight satellites, taken in their order from their planet, cover spaces on the Saturnian heavens which bear to the space covered by our moon the respective proportions of about 2, 1, $1\frac{1}{4}$, $\frac{3}{4}$, $\frac{5}{8}$, $\frac{1}{3}$, $\frac{1}{100}$, $\frac{1}{40}$. In all, then, they cover an area about six times that of our moon; and as, owing to their great distance from the sun, they are illumined by only $\frac{1}{100}$th of the light which illuminates our moon, they could only send back to the planet, if it were possible for them to be all full together, about $\frac{1}{16}$th part of the light we receive from the full moon. It will be remembered that the light which would be reflected from the Jovian moons, if they could be all full together, bears about the same propor-

tion to our moon's. We seem forced to the conclusion that the satellites were not intended to subserve any such design as has been imagined. Here, as in many other cases, the scheme of creation is not so obvious to human reasoning as some have complacently supposed.

But we have now to consider peculiarities which suggest that Saturn's globe has not yet reached a condition fitting it to be the abode of living creatures. These peculiarities resemble in great part those which have been already noticed in the case of Jupiter, but a certain most remarkable phenomenon belongs to the ringed planet alone.

The belts of Saturn resemble those of Jupiter in their general shape (see the accompanying Plate) and also in their colour. The dark belts near the equator are of a faint brown or ruddy tinge, those near the pole bluish or greenish grey, while the bright belts are yellowish—the equatorial belt being the brightest of all, and almost white. The poles are commonly dusky, and even sombre in hue.

The belts change in aspect much as those of Jupiter have been observed to do; and whether we regard the change as due to the bodily transference of the belts of cloud or to the precipitation of their material in the form of rain (while, elsewhere, invisible vapours are condensed into clouds), we are compelled to recognise the action of forces altogether exceeding those which the sun can be supposed to exert upon this distant planet. The light sent to us from Saturn also bears a much greater proportion to the amount of solar light



THE PLANET SATURN.

actually received by the planet than is observed in the case of Mars or the moon, and so nearly approaches the proportion noticed in the case of Jupiter as to lead to the same inference—namely, that a portion of Saturn's light is emitted from the body of the planet.

In these respects, and also in the small density of the planet, we seem to recognise evidence which points to Saturn as probably a heat-sun (if not to any very noteworthy extent a light-sun) to the satellites which circle around him, and not himself the abode of living creatures. Without dwelling further on evidence already fully considered in the case of Jupiter, I turn to one of the most striking facts in the whole range of observational astronomy, as supplying at once new evidence respecting the condition of Saturn, and strengthening the evidence adduced respecting Jupiter.

If it can be shown that Saturn's globe is subject to changes of figure perceptible even across the enormous gap which separates him from the earth, it will at once be admitted that he can hardly be regarded as a globe conveniently habitable. Now I have very little hesitation in saying that evidence of the most conclusive kind exists in favour of this strange mobility of figure. It will presently be seen that it is with the observations of no mere amateur astronomers that I have to deal in endeavouring to establish as a fact that which has commonly been spoken of as an illusion—the assumption by Saturn of his so-called 'square-shouldered' figure.

It was in April 1805 that Sir William Herschel first called attention to this peculiarity. The planet, which had always presented to him an elliptical figure, exhibited a strangely distorted aspect. A well-marked flattening at the equator, accompanied by an equally well-marked flattening at the poles, gave the planet's globe an oblong figure (with rounded angles), the longest diameters having their extremities in Saturnian latitude 48° 20′—so exactly was the great astronomer able to indicate the nature of the deformity, owing to its well-marked character.

What view shall we form respecting an observation of so remarkable a nature? Was the peculiarity due to telescopic distortion? Herschel observed it with several instruments, some seven, some ten, one twenty, and one forty feet in length. Was the phenomenon due to atmospheric disturbances? Such disturbances could not account for a persistent impression, however well they might explain the momentary assumption of the square-shouldered aspect by the ringed planet. Besides, Jupiter presented no such appearance. Was the appearance an optical illusion, due to the position of the ring—then slightly open? If so, the planet should always exhibit the square-shouldered aspect when his rings are open to that particular extent; and this is not the case. Besides, we ought to notice a similar illusion when looking at a picture representing that particular phase of Saturn. Must we then accept the astounding conclusion that the giant bulk of Saturn is subject to throes of so

tremendous a nature as to upheave whole zones of his surface five or six hundred miles above their ordinary level? Truly the conclusion is one to be avoided, if we can by any possibility find a less startling explanation of the matter.

Yet where are we to look for such an explanation? Was Sir William Herschel simply deceived? I have already considered the general question of illusion, but the reader might entertain the explanation as conceivable that Herschel had for a while lost the acumen which distinguished him—that illness, for example, might have rendered his observations inexact. But we have abundant evidence that the great astronomer was in the full possession of all his wonderful powers as an observer during the month of April 1805; we know further that, by careful measurements, he rigidly excluded all possibility of illusion affecting his judgment.

It would be more satisfactory, doubtless, to the reader, however, to learn that other observers had noticed similar peculiarities, or peculiarities which, if not similar, were at least such as to prepare us to consider the globe of Saturn liable to remarkable changes of figure. Fortunately many such observations have been recorded. I take the following from one of a lengthy series of papers on Saturn by Mr. Webb, in the 'Intellectual Observer' for 1866.

On August 5, 1803, Schröter found Saturn not perfectly spheroidal in figure. Kitchener says that for a few months in the autumn of 1818 he saw Saturn of

the figure described by Sir William Herschel, and that with two different achromatics. At this time the ring must have appeared too narrow to account for the appearance as due to illusion. On one occasion Sir George Airy had a similar view of Saturn. He remarks, also, that a person unacquainted with Herschel's observation remarked spontaneously on the flattened equator of the planet. On another occasion, Sir G. Airy noticed the exact reverse, the planet seeming flattened, instead of upheaved, in latitude 45°. In January 1855, Coolidge, using the splendid refractor of the Cambridge (U.S.) Observatory, noticed that the greatest diameter of the globe seemed inclined about 20° to the equatorial diameter; but on the 9th the equatorial diameter seemed the greatest; while on December 6 he says: 'I cannot persuade myself that it is an optical illusion which makes the maximum diameter of the ball intersect the limb half-way between the northern edge of the equatorial belt and the inner ellipse of the inner bright ring.' All this time the rings were nearly at their greatest opening, so that any illusion should have been of an opposite character to that observed when the rings were nearly closed. In the report of the Greenwich Observatory for 1860–61 it is stated that 'Saturn has *sometimes* appeared to exhibit the square-shouldered aspect.' The eminent observers Bond, father and son, have noticed similar peculiarities, using the great Merz refractor already referred to. Each of them noticed a flattening of the north-polar regions of the planet in the summer

of 1848, when the ring was turned edgewise towards us. On the other hand, the same observers noticed that in 1855–57, when the ring was most widely opened, the polar region did not always seem projected farthest on the outer ring in a symmetrical manner, but four times on the left of the pole, once on the right, and once only exactly opposite the pole. 'The outline of this region, also, occasionally appeared irregularly flattened and distorted,' an appearance not satisfactorily explained by the juxtaposition of the dark shadow of the planet on the ring.

Now there can be no doubt whatever that the planet Saturn is not ordinarily distorted. In 1832, during the disappearance of the ring, Bessel carefully determined the figure of the planet's disc, and Main in 1848 (when the ring was again turned edgewise towards us) made similar measurements. Each of these trustworthy authorities came to the conclusion that the disc of Saturn did not, at the seasons when they respectively measured it, exhibit any distortion of figure such as Herschel had described.

We seem almost compelled, therefore, to accept the conclusion that the planet Saturn is subject to the influence of forces which either upheave portions of its surface from time to time, or cause vast masses of cloud to rise to an enormous height above the mean level of Saturn's cloud-envelope. Whichever view we adopt, we cannot fail to recognise the fact that an intense heat must in all probability prevail in the great globe of Saturn; and doubtless the real mass of the

planet must emit a brilliant light, though the cloud-strata surrounding him may prevent us from recognising more than a minute proportion of his luminosity. In fact, according to this view, Saturn and Jupiter, unlike the sun, whose real substance emits a less intense light than the cloud photosphere surrounding him, must have nuclei—solid or liquid—shining with an altogether more brilliant light than the cloud-envelopes of these planets seem actually to emit.

Why Saturn, rather than Jupiter, should exhibit from time to time these mysterious changes of figure is readily explicable when we remember that the plane in which the Jovian satellites move nearly coincides with the orbital plane of their primary. There thus always results a close agreement between the zone on which the satellites exert their greatest disturbing influences and that most influenced by the solar action. No such coincidence exists in the case of Saturn, whose satellites travel in a plane inclined nearly 30 degrees to that in which their primary travels. We have seen, however, that evidence is not wanting to prove that Jupiter is really liable to occasional changes of figure, though not to such an extent as to change the general aspect of the planet.

I think the evidence in the case of Saturn favours, at least as strongly as that which has been adduced in the case of Jupiter, the belief that the giant planets outside the zone of asteroids are not themselves suitable abodes for living creatures, but are suns, supplementing the small amount of light, and yet more

fully supplementing the small amount of heat which the sun supplies to the satellites circling around these orbs. Undoubtedly, if we are to judge according to the method which has been so often applied to such questions, if we are to ask ourselves according to what arrangement the central planets and the systems circling round them seem most reasonably interpreted, we should at once adopt some such conclusion. For, by taking Jupiter and Saturn to be strictly analogous to our own earth, and their satellites to be subsidiary bodies, resembling our moon in *this*, that they subserve at present no other purpose but to illuminate the nocturnal skies, and to sway the oceans of their primaries, we find ourselves perplexed by the consideration that a much simpler arrangement would have subserved these purposes much more completely. In the case of Saturn's satellites, indeed, it seems difficult to conceive that these bodies could have been intended to fulfil any such purposes, since the two outer ones could neither give any useful light to their primary, nor sway appreciably any oceans which may exist upon the planet.

These considerations lead me to believe that the two most important members of the planetary scheme must be left without inhabitants for the present, while in exchange I submit, to the contemplation of the curious, twelve small orbs, constituting two miniature world-systems. The condition of these worlds will be touched on briefly in a separate chapter.

CHAPTER VII.

URANUS AND NEPTUNE, THE ARCTIC PLANETS.

A CIRCUMSTANCE which is of great importance in considering the relations of the outer planets is apt to be lost sight of, owing to the unsatisfactory manner in which in nearly all books on astronomy the planetary orbits are represented. To look at the series of equidistant and concentric circles representing the orbits of the planets, who would suppose that in passing from the orbit of Jupiter to that of Saturn a distance five times as great as that which separates our earth from the sun has to be traversed? But the distance separating Uranus from Saturn is twice as great even as this tremendous gap, while Neptune travels as far beyond Uranus as Uranus beyond Saturn. Nine hundred millions of miles in width is the enormous gap by which the path of Uranus is separated from that of the ringed planet on the inner side, and from that of distant Neptune on the outer; so that a line equal to the diameter of Jupiter's orbit would barely suffice to reach from Saturn to Uranus, or from Uranus to Neptune, even when either pair of planets are in conjunction.

We know so little of the physical aspect of Uranus and Neptune that it is extremely difficult to form any opinion as to their condition. The two planets resemble each other in size, each being far smaller than either of the giant orbs we have lately been considering. Uranus has a diameter of about 33,250 miles; Neptune is somewhat larger, his diameter having been estimated at 37,250 miles. The volume of Uranus is 74, the volume of Neptune 105 times that of the earth. Both planets exceed Saturn in density; for whereas Saturn's mean specific gravity is but $\frac{13}{100}$ths, that of Uranus is $\frac{17}{100}$ths, and that of Neptune $\frac{16}{100}$ths of the mean specific gravity of our globe. Thus each planet has a density nearly equal to that of water. The mass of Uranus exceeds the earth's about $12\frac{1}{2}$ times, while that of Neptune is some $16\frac{3}{4}$ times as great as the earth's. It will be seen, therefore, that though these two far-distant worlds are much less massive than Jupiter or Saturn, each of them outweighs many times the combined mass of the four planets which travel within the zone of asteroids. Yet gravity on the surface of these two orbs is but about three-fourths of terrestrial gravity.

The disc of the sun as seen from Uranus is less than that which we see, in the proportion of 1 to nearly 390, while the Neptunians have a sun only about $\frac{1}{900}$th of ours in apparent size; and in these proportions the solar light and heat received by these planets are respectively diminished. So small does the sun appear, in fact, that to eyes such as ours his orb would not

present a disc-like figure, but would appear like an exceedingly brilliant day-star.

So far we have found the circumstances of the two planets somewhat similar. But we have now to consider a relation presented by Uranus, which is not shared in by Neptune. It may be remarked that we know so little about either planet that any very careful consideration of their habitability would be simply a waste of labour. The evidence I am about to adduce, however, in the case of Uranus, seems thoroughly to dispose of the claim of this planet to be regarded as a world inhabited by creatures resembling those we are acquainted with on earth; and as we cannot reasonably suppose Neptune to be inhabited by such creatures while Uranus is not, we may very fairly regard the question as disposed of for both planets, even though the relation dealt with is peculiar to Uranus.

Uranus has a family of four satellites, Neptune has only one satellite yet discovered. Now we know that in the case of Jupiter, as in that of Saturn, the position of the plane near which the satellites travel is nearly coincident with the plane of the primary's equator. Therefore, though no telescope has yet exhibited any features on the discs of Uranus or Neptune which can enable us to determine the position of its equator, we can safely infer from the motion of the satellites how the equators of the planets are situated.

Now the satellites of Uranus travel in a plane very nearly at right angles to the plane in which the planet travels. It may be mentioned also, though not im-

portant for my present purpose, that they travel in a retrograde direction. The satellite of Neptune travels in a path not inclined more than about 27° to the plane of the planet's path; but the motion of the satellite is retrograde. We conclude that the axis of Uranus lies very nearly in the plane wherein the planet moves around the sun, and that the planet rotates in such a way around this axis that the sun moves across the Uranian skies from west to east, instead of from east to west. The latter relation is of no great importance; the former, however, involves results which dispose at once, and thoroughly, of any hopes we might entertain of discovering creatures in Uranus resembling those which inhabit the earth.

The inclination of the plane of Uranus's equator to the path in which he travels being about 76°, it follows that the Uranian sun has a range of about 76° on either side of the celestial equator, during the long Uranian year. Already, in considering the seasons of Venus, I have dealt with a peculiarity of this sort; but in the case of Uranus the effects are more serious. We have only to consider what would be the result of so wide a range of solar excursion north and south of the celestial equator in a latitude corresponding to that of London, to see how importantly the climatic relations of a planet like Uranus, occupying eighty-four years in circling once round the sun, must be affected by such a peculiarity. We know that in the latitude of London the sun reaches at noon, in spring or autumn, an elevation of about 38½ degrees above the southern horizon, that

in summer he passes the meridian $23\frac{1}{2}$ degrees higher, while in winter he passes the meridian $23\frac{1}{2}$ degrees lower, or only 15 degrees above the horizon. But in a similar Uranian latitude, while the sun would reach the same meridian elevation in spring or autumn, he would in summer travel throughout the day in a small circle, 14 degrees only from the pole (raised of course $51\frac{1}{2}$ degrees above the horizon), so that at noon he would be $65\frac{1}{2}$ degrees, and at *nominal* midnight $37\frac{1}{2}$ degrees above the northern horizon. And obviously, since the year of the Uranians lasts 84 of our years, the continuance of the sun above the horizon would last for many years.[1] So far there is nothing to render life in Uranus unpleasant, always supposing the small amount of light and heat supplied by the sun to be compensated by some such atmospheric arrangements as physicists have thought necessary for the convenience of the more distant planets. But when we consider the nature of the Uranian winter, we find the circumstances such as no arrangements of the sort can be conceived to alleviate. The winter path of the Uranian sun, in a latitude corresponding to that of London, is just as fully depressed below the horizon as the summer path is raised above it. At midnight the sun

[1] Exact calculation applied to relations so uncertain as those here in question would be out of place. From a careful construction, however, with 76° as the assumed value of the inclination of the equator of Uranus to the plane of his orbit, I find that the sun would continue above his horizon in summer for about $23\frac{1}{2}$ years. Of course it follows that the sun would continue below the horizon for an equally long period in winter!

is $65\frac{1}{2}$ degrees, at nominal noon he is $37\frac{1}{2}$ degrees below the southern horizon. And as with the summer day, so with the winter night, years elapse before either comes to an end. For upwards of 20 years, in a latitude corresponding to that of London, the Uranians —if there are any—never see the small Uranian sun. During all this long time, too, a sight even is denied them of all parts of the solar system interior to the orbit of Uranus; though this deprivation cannot be regarded as very serious when it is remembered that to such eyesight as ours Saturn would barely be visible from Uranus, even when most favourably situated, while Jupiter, always near the sun, would only be occasionally seen, shining with a light somewhat less than a fiftieth of that which he reflects to us when in opposition.

When we consider other latitudes, we find Uranus ill provided for as respects his winter season. In all latitudes nearer the pole than the latitude just considered, the Uranians have winters lasting from twenty years to upwards of forty. In latitudes nearer the equator the winter night is shorter, but we must approach quite close to the equator before we reach a latitude where the winter night lasts less than a year or so. Over a belt extending about 14 degrees on each side of the equator there is a perennial succession of days and nights never exceeding the full duration of the Uranian diurnal rotation. But we must not suppose that we have thus found an Elysian zone in Uranus. The immense range of the sun's excursions

produces here also a variety of seasonal changes which we should find altogether unendurable. From a sun barely rising above the horizon in winter, to a sun which rises vertically overhead twice in the course of the Uranian summer, is a change which hardly accords with our views of what is desirable in the progress of the seasons. At the equator itself there are in reality two summers, occurring at the period of the sun's passing the celestial equator. Here for many years together the sun passes day after day to a point nearly overhead. But then comes the long winter, in the heart of which the sun rises barely 14 degrees above the northern or southern horizon. By whatever arrangement we render the long Uranian winters in this part of the planet endurable, we render the heat of his long summers unbearable; and *vice versâ*, if we conceive of atmospheric relations which would render his summers pleasing, we have caused his winters to be so intensely cold that no creatures we are familiar with could endure the prolonged and bitter frosts, contrasting so distressingly with the imagined geniality of his summer weather.

If Uranus be inhabited at all, then, it must be by creatures constituted in a very different manner from any with which we are acquainted. To such creatures, if any among them be gifted with intelligence, the heavens, though not adorned with planets, must yet present an interesting subject of study. The position of the pole, lying close by the zodiac, so that amongst the zodiacal constellations there are all the varieties

of motion which we recognise in passing from the equatorial to polar constellations, would lead to a certain complexity in celestial charts and globes, which would invite us to the conclusion that the Uranians must be capital mathematicians. Then there are certain astronomical subjects of study to which their mathematical powers may be devoted perhaps more successfully than those of our astronomers. For example, the wide sweep of the planet's orbit would enable the Uranians to recognise a displacement of the stars in the course of the long Uranian year. The star Alpha Centauri, which only exhibits to the terrestrial observer an annual parallax of one second, would exhibit to the observer on Uranus a displacement of about the third part of a minute. Other stars would be affected in like proportion, and perhaps the Uranians may thus be enabled to form some conception of that relation which hitherto has proved too baffling a problem to our astronomers—the actual configuration of the nearer parts of the sidereal system. The Neptunians would of course be even more favourably circumstanced.

One difficulty presents itself, however, in thus considering the prospects of the Uranian and Neptunian astronomers. The enormous length of the year of each planet requires that either the astronomers in Uranus and Neptune should be very long-lived, or that they should be very enthusiastic in the cause of science, to prosecute singly such observations as Henderson, Olbers, or Peters, have singly prosecuted

on our earth. An Uranian who made one set of observations to determine stellar parallax when he was, say, twenty-five years old, would have to wait till he had nearly reached the threescore years and ten (not perhaps allotted as the span of Uranian life) before he could make the corresponding set, by comparing which with the former, stellar parallax was to be determined. In Neptune life must be prolonged over the century (unless the study of observational astronomy commence during the babyhood of the Neptunians), in order that a complete set of observations for determining stellar parallax should be carried out. One cannot but conceive that a certain sluggishness would mark the progress of astronomy in these far-off worlds under such circumstances. In fact, the mere consideration that after a constellation has passed away from the nocturnal skies of Uranus or Neptune, 30 or 40 years in one case and 70 or 80 in the other must pass before the constellation again becomes favourably visible, suggests characteristics of astronomical observation altogether different from those we are familiar with.

Admiral Smyth suggests that these distant planets must be convenient outposts for watching the approach or recession of comets; but I venture to point out that the inhabitants of the earth are on the whole more favourably situated in this respect. Every large comet which approaches tolerably near to the sun during perihelion passage is as likely to be seen as to be missed by the inhabitants of earth; but scarcely one out of a thousand such comets would be seen

from Uranus or Neptune, since to be visible a comet must approach the sun or recede from him along a course passing tolerably near to the particular position of either planet at the time; and the changes in the case of any individual comet would be enormously against such a contingency.

With eyesight such as ours the Uranians would distinctly see Neptune when in opposition, but the Neptunians would be wholly unable to see Uranus, or indeed any known planet of the solar system.

Perhaps, though we have very little evidence on the point, it will be thought more reasonable to suppose that Uranus and Neptune are suns to their respective systems of satellites, than to imagine that these two drearily circumstanced planets are themselves inhabited. Their satellites cannot possibly compensate to any noteworthy extent for the small amount of solar light or heat which reaches their primaries. On the other hand, it is not difficult to conceive that the planets may afford an important supply of heat (at any rate) to their dependent orbs. Certainly, so far as the evidence we have extends, Uranus and Neptune resemble Saturn and Jupiter too closely not to warrant the application of any arguments deduced from the appearance of the two giant planets to the case of their inferior but still gigantic brethren.

Viewing the matter thus, we seem led to the conclusion that the planets which lie outside the zone of asteroids are distinguished from those within that belt, not merely, as had so long been recognised, by the

attributes of size, density, rapidity of rotation, and the complexity of systems circling round them, but in this more important and more interesting circumstance, that they and their dependent orbs are real miniatures of the solar system. Four suns they would seem to be, not indeed suns resplendent like the primary sun round which they travel, yet giving out perhaps no insignificant supply of light; not heated to incandescence as he is, but still supplying an amount of heat proportionately far greater than the quantity of light they give forth: in fine, not, as he is to the inner planets, the sole source whence all supplies of force are derived, but adding their influence to his in a variety of complicated but doubtless well-ordered combinations, in such sort that the small worlds which circle around them are provided with all that is necessary for the well-being of their inhabitants.

CHAPTER VIII.

THE MOON AND OTHER SATELLITES.

ALTHOUGH the moon cannot be regarded as at present the abode of any forms of life, such as we are familiar with on earth, there are many reasons for studying in a work on other worlds the various relations she presents to us. In the first place, she subserves various useful purposes in the economy of our own earth; then there are circumstances in her appearance which suggest that at one time there may have been life upon her surface; and lastly, she affords us the only information we have concerning the probable relations presented by the noble systems of moons which circle around Jupiter and the other planets outside the zone of asteroids.

With regard to the present habitability of the moon, it may be remarked that we are not justified in asserting positively that no life exists upon her surface. Life has been found under conditions so strange—we have been so often mistaken in assuming that *here* certainly, or *there*, no living creatures can possibly exist—that it would be rash indeed to dogmatise respecting the state of the moon in this respect.

Still, in the case of the moon we have relations

wholly different in character from those we have hitherto had to consider. We no longer have to deal with various degrees of heat and cold, of atmospheric rarity or density, and the like, but with relations which do not in the slightest degree resemble those we are familiar with on earth.

In the first place, the moon has no appreciable atmosphere. We have long known this quite certainly, because we see that when stars are occulted by the moon they disappear instantly, whereas we know this would not be the case had the moon an atmosphere of appreciable extent. But if any doubt could have remained, the evidence of the spectroscope in Mr. Huggins's hands would have sufficed to remove it. He has never been able to detect a sign of the existence of any lunar atmosphere, though Mars and Jupiter, so much farther from us, have afforded distinct evidence respecting the atmospheres which surround them.

Then secondly, there are no seas or oceans on the moon. Were there any large tracts of water, the tremendous heat to which the moon is subjected during the course of the long lunar day (lasting a fortnight of our time) would certainly cause enormous quantities of water to evaporate; and not only would the effects of this process be distinctly recognisable in the telescope, but the spectroscope would exhibit in an unmistakable manner the presence of the aqueous vapour thus formed.

Thirdly, there are no lunar seasons. The inclina-

tion of the moon's axis to the orbit in which she travels round the sun is nearly 89°, and with this inclination there can be no appreciable seasonal changes.

Fourthly, the enormous length of the lunar day is altogether opposed to our conceptions of what is suitable for animal or vegetable life. The lunar day lasts about a fortnight, and the lunar night is, of course, equally long. Were this all, the inconvenience of the arrangement would not be endurable by beings like ourselves. But far more serious consequences must result from the combination of the arrangement with the want of an atmosphere; for whereas during the lunar day the surface of the moon is exposed to an inconceivably intense direct heat, undoubtedly sufficient to heat that surface far above the boiling point, during the lunar night the heat is radiated rapidly away into space (no atmosphere checking the process), and an intensity of cold must prevail of which we can form but imperfect conceptions.[1]

The mere fact that our earth is always invisible from

[1] The moon's physical habitudes are in fact so very different from those of the earth that one cannot read without astonishment the following passage in which Sir W. Herschel pleads for the moon's habitability. 'Its situation, with respect to the sun,' he says, 'is much like that of the earth, and by a rotation on its axis it enjoys an agreeable variety of seasons (!) and of day and night. To the moon, our globe will appear to be a very capital satellite, undergoing the same regular changes of illumination as the moon does to the earth. The sun, the planets, and the starry constellations of the heavens will rise and set there as they do here, and heavy bodies will fall on the moon as they do on the earth. *There seems only to be wanting, in order to complete the analogy, that it should be inhabited like the earth.*' The evidence, however, seems to me to lie all the other way.

three-sevenths of the moon's surface is one which points very strongly to the conclusion that the present condition of the moon is not the one best calculated to meet the wants of living creatures on her surface. In long-past ages, when her rotation had not yet been forced into accordance with her revolution[1] (as at present), the earth must have subserved a variety of most important purposes. If water then existed on the surface of the moon, the earth must have raised tidal waves in the lunar oceans. She must further have reflected enormous supplies of light and heat towards her dependent orb, even if at that time she were not a secondary sun for the lunarians. She must have travelled across the lunar skies as the moon travels over ours, presenting a variety of interesting and beautiful phases, affording useful time-measures, and so enabling the travellers on the moon in those long-past ages to guide their course in safety over her oceans or her deserts. But now she is invisible from a large

[1] The researches of Adams into the peculiarity of the moon's motion called her acceleration, suffice to show that under the influence of the moon's attraction on our oceans, the earth's rotation is gradually diminishing; so that, though many millions of ages must elapse first, she will one day so rotate as to keep always the same face turned towards her satellite. We cannot doubt that it has been by a process of this sort that the moon's rotation has been brought to its present rate. In fact, independently of the evidence afforded by the earth's gradual loss of rotation, we cannot account for the moon's peculiarity of rotation without regarding it as due to the earth's controlling influence. A perfectly homogeneous sphere, started on a direct line at the moon's distance, and with the same velocity, would travel without rotation on an orbit like the moon's, and would thus in completing a revolution exhibit every part of its surface to us.

portion of the moon's surface, and almost a fixture in the skies even of those parts of the moon whence she can be seen. Were there lunar oceans, she could raise no tides in them. Were there a lunar atmosphere, she could shed no heat, to be garnered up, so to speak, by that atmosphere, and to compensate, in some sort, for the long absence of the sun.

But have we evidence that at some far-distant epoch the moon was inhabited? Taking for our guidance the analogies which are available to us, can we really conclude that once, in all probability, those barren wastes were clothed with vegetation, those dreary solitudes the abode of life?

When we contemplate with attention the lunar surface, considering the indications it presents of past activities, we are led to inquire how the forces which have been so busily at work were expended. If Nature, studied thoughtfully, teaches us the lesson that there is no form of force which is not the representative of some other pre-acting form of force, she also teaches us that no form of force ever works without generating other forces as its own energies are expended. The meteor which sweeps with planetary velocity through space may be brought to rest upon the sun, but the energy stored up in its motions is not wasted; the sun may expend the stores of force he derives from meteoric impact, but not idly;[1] all

[1] The question may be asked, What becomes of the immense supplies of light and heat continually poured by the sun and other stars into space? We cannot tell; yet we know certainly that they cannot be wasted. The heat of Arcturus, measured by Mr.

round us we see the fruits of solar energies, we feel them within ourselves, we exert them upon others. And therefore when we see on the moon signs that her surface was at one time upheaved by tremendous volcanic forces, we are led to the conclusion that between the era when she was thus disturbed, and the present time, when she seems absolutely quiescent, there must have been a period when her energies were fit for sustaining various forms of life; though it does not follow, of course, that they were so employed. There *has*, in this instance, been a process resembling exhaustion, though we know that the forms of force which have passed away from the moon have not really ceased to exist; but before the lunar forces were dissipated into space, they may have subserved the purpose of supporting life.

Associated, however, with this subject, there are

Stone, gives an account of one large portion of the stellar heat supplies, because we know that, small as the amount we receive may be, we must multiply that amount millions on millions of times to get the total received by all the orbs in space from this particular sun. But we know that a large portion of our sun's light and heat must either fail to fall on any other orbs, or must be gradually exhausted in its progress through space (for if lines from the sun in every direction encountered orbs, the sky ought to be lighted up at all times with star-splendour—which is no other than sun-splendour). In either case we cannot tell what becomes of the portion seemingly wasted; though in the latter case we may affirm confidently that there is simply a change in the nature of the energy. In both cases we know that the total of energy in the universe remains undiminished. There is, indeed, a seeming contradiction here; but it is not different in character from the seeming contradictions suggested by the consideration of infinite space and infinite time, which yet we are compelled to recognise as absolutely as finite space or finite time.

questions of a perplexing character, which invite our careful consideration. If life ever existed on the moon, she must have possessed an atmosphere and seas. Independently, also, of our views on the subject of life upon the moon, we are led by the revelations of the spectroscope respecting the solar system, to believe that all the bodies within that system are in a general sense similarly constituted; and if this be so, there must once have been oceans and air upon the moon. What has become of the moon's atmospheric envelope, and of the lunar oceans?

In four several ways this question has been answered. Some have thought that the oceans and air have been withdrawn into cavities within the moon's substance. Others have imagined that the air and oceans may have passed away to the farther hemisphere of the moon. According to a third theory, a comet has carried off the lunar oceans and atmosphere. And lastly, a fourth theory has been maintained, according to which the lunar air, and *à fortiori* the lunar seas, have been changed by intensity of cold into the solid form.

Of these theories, the first and last only seem worthy of consideration. We see so much of the moon's farther hemisphere during her librations that we must perforce reject the second, even if we had any trustworthy reason for believing so strange an arrangement to be possible.[1] The third theory is

[1] Professor Newcomb, of America, has shown excellent reasons for doubting whether even that displacement of the moon's centre of

opposed by all that modern astronomy teaches respecting the constitution of comets.

The theory that an atmosphere formerly surrounding the moon has passed with the lunar oceans into the interior of our satellite has been supported by physicists of considerable eminence. The relatively low specific gravity of the moon (little more than half the earth's) suggests the possibility that cavities large enough to contain even all the waters of our own oceans may exist within the moon. Nor does the fact that we can see no unmistakable signs of chasms extending deep into the moon's substance suffice to render the theory untenable, or even improbable. It is difficult to understand how the retreat of the waters took place. Certainly it cannot have happened while the moon's volcanic forces were in vigorous action; yet a period must undoubtedly have arrived when by little and little the waters could retire within the moon's substance without being vaporised. From what we know of volcanic action on the earth, the lunar volcanoes must have drawn fresh supplies of energy from the gradual influx of water; and one can thus understand why the aspect of the moon indicates that up to the last moment, so to speak, of her exist-

gravity, on which the theory has been based, can be admitted as an established fact. Independently of this, however, the theory will not bear close examination. Anyone who will draw a cross section of the moon (in a plane passing through the earth), and endeavour to assign such a position to an atmosphere of moderate extent that even during the moon's extreme librations no signs of the atmosphere would be perceptible from the earth, will at once see that the theory is untenable.

ence as a world, the forces upheaving her crust were busily at work. We can thus see how it has come to pass that the moon's surface shows so few signs of the action of rain or running water.

The theory that the lunar oceans have become frozen, and that afterwards even the gases forming the lunar atmosphere have become solidified, was maintained by Buffon and Bailly in the last century, and has been supported by several astronomers in our own day. In some respects, the aspect of the moon (especially the absence of well-marked colours from her surface) seems to favour the theory. Nor need the excessive heat to which the moon's surface is exposed for weeks at a time, be considered a sufficient reason for rejecting it, because we have no means of judging how that heat would act where there is no atmosphere to prevent its immediate and entire reflection into space. We know that despite the intense heat which is poured upon the summits of the Himalayas, the snow there—though a portion may melt during the day—remains year after year and age after age undiminished; and on the summit of the Himalayas the atmosphere is dense and heavy compared with that which exists even in the lowest abysms of the lunar ravines. But the results which have been deduced from the application of Lord Rosse's three-feet mirror to the measurement of the lunar heat, compel us to abandon the belief in the existence of frozen oxygen or nitrogen on the moon's surface, since, according to those results, a large proportion of the

moon's heat is radiant—in other words, the moon's surface has been actually raised to a high degree of heat by the solar rays. Most physicists look with considerable confidence on the method by which, in the researches made at Parsonstown, an attempt has been made to distinguish between the heat which the moon reflects and that which she radiates into space.

On the whole, therefore, the former theory seems to have the strongest evidence in its favour, or rather the least decisive evidence against it.

In considering the systems of bodies which circle around the outer planets, we are struck at once by several marked circumstances of contrast between their condition and that of our own moon.

In the first place, we have no satisfactory evidence that the satellites of Jupiter and Saturn turn always the same face towards their primary. It is true that Sir William Herschel was led by certain observations of the satellites of Jupiter to conclude that this relation holds in their case. But we have far stronger evidence against such a view, in the fact that modern observers armed with telescopes of the most exquisite defining powers have not only been unable to confirm the relatively rough observations made by Herschel, but have noticed peculiarities of appearance only explicable by the theory that the rotation of the satellites is quite independent of their motion of revolution around Jupiter. Dawes, for instance, has observed that the markings seen on the third satellite, when transiting Jupiter's disc, are variable. Bond has seen this satel-

lite as a well-defined black spot on certain occasions, while on others it has appeared quite bright on the disc of the planet. He once saw this satellite bright as it entered on the disc of Jupiter, and about half an hour later as a dark spot; while Mr. Prince, with a powerful reflector, has seen the satellite dark first and afterwards bright. It need hardly be said, that if the satellite turned always the same face towards its primary no such varieties of appearance would be presented during transit. The following passage from Webb's 'Celestial Objects' points strongly also to the conclusion that the rotation of the Jovian satellites must be independent of their revolution. After mentioning that the variable light of the satellites may be caused by the existence of spots upon their surface, he proceeds: 'A stranger source of anomaly has been perceived—the discs themselves do not always appear of the same size or form. Maraldi noticed the former fact in 1707, Herschel ninety years afterwards inferring also the latter, and both have since been confirmed. Beer and Mädler, Lassell and Secchi, have sometimes seen the disc of the second satellite larger than that of the first; and Lassell, and Secchi and his assistant have distinctly seen that of the third satellite irregular and elliptical; while, according to the Roman observers, the ellipse does not always lie the same way.'

It will easily be seen that these peculiarities indicate the existence of dark markings on these bodies, and that, as the satellites rotate, the varying position of these markings causes the satellites seemingly to

change in figure since the brighter part of the satellite would be that which would determine its apparent figure. And further, since the change of figure shows no correspondence with the position of the satellites in their revolution, we infer that their revolution is independent of their rotation.

It is worthy of notice, however, that even if the inner satellites turned always the same face towards their primary, the peculiarity would not (as in the case of our moon) result in an inordinate lengthening of their diurnal period, since Jupiter's two inner satellites complete a revolution in 1 day 18½ hours, and 3 days 13 hours respectively; while the revolutions of Saturn's five inner satellites are severally accomplished in 22½ hours, 1 day 9 hours, 1 day 21 hours, 2 days 18 hours, and 4 days 12½ hours.

So far as we can judge from Laplace's estimates, the specific gravity of Jupiter's moons must be very small, ranging from one-third to two-thirds of the moon's specific gravity. But very little reliance can be placed on these results, because the only evidence we have respecting the mass of the satellites is that founded on the perturbations to which their motions are subjected, and it is very difficult indeed to estimate these perturbations. When to this we add the circumstance that little reliance can be placed on measurements of the minute disc presented by the satellites, it will be seen that our estimate of the specific gravities of these bodies cannot by any means be regarded as trustworthy.

As seen from his satellites, Jupiter must present a magnificent scene. To the inhabitants, if such there are, of the innermost satellite, he exhibits a disc nearly twenty degrees in diameter. Thus, whereas there might be about 700 moons such as ours placed all round our horizon, the disc of Jupiter, as seen from the inner satellite, would occupy a full eighteenth part of the horizon's circumference. The disc of Jupiter, as so seen, would cover a space on the heavens exceeding more than 1,400 times that which our moon covers. To the second satellite, Jupiter presents a disc about 12½ degrees in diameter, or about 600 times as large as our moon's. To the third satellite he shows a disc about 7¾ degrees in diameter, or more than 200 times the size of the moon's. And lastly, the inhabitants even of the furthermost satellite see him with a diameter of about 4½ degrees—that is, with a disc more than 65 times as large as that of our moon. So that, if the views I have put forward respecting Jupiter be correct, the enormous space he covers on the skies of his respective satellites must suffice to compensate in part for the relatively small amount of heat which he can be supposed capable of emitting.

If the satellites rotate with a motion independent of their revolution, Jupiter passes across their skies like a vast moon, exhibiting phases such as those presented by ours, but on a far vaster scale. But besides his phases, he must exhibit to the inhabitants of his satellites the most marvellous picture that can be conceived. His belts' changes of figure and colour, only rendered

visible to our astronomers by powerful telescopic aid, must be distinctly visible to creatures on his satellites, and cannot but afford reasoning beings on those orbs a most astounding theme for study and admiration.

To the inhabitants of the satellites which circle round Saturn, the ringed planet must present an even more interesting spectacle. His disc as seen from the nearest of his satellites has a diameter of 17 degrees and an apparent surface exceeding more than 900 times that of the moon. From the farthest satellite his disc is less than a degree in diameter, and therefore not quite four times as large as our moon's. Between these limits the apparent size of Saturn varies as we pass from satellite to satellite; but from the sixth satellite his apparent surface is twenty-five times, while from the seventh it is sixteen times as large as the moon's; so that the outer satellite is quite exceptionally circumstanced in this respect.

It is not so much from the apparent size of his disc, however (though in the case of all the inner satellites that must be a most remarkable relation), as from the peculiar character of his ring-system, that Saturn would derive his chief interest. It is true that the inner satellites travel nearly in the plane of the rings, so that these are always presented nearly edgewise. But even so viewed, the rings would present a most striking appearance. From the inner satellite, indeed, the extreme span of the ring-system is more than 90 degrees;[1] so

[1] About 93° according to the best estimates of the dimensions of the rings and the distance of the satellite.

that when one extremity is seen on the horizon the system would appear as an arch thickest in the middle, extending over an arc of about 93 degrees, and having the disc of Saturn at its centre. When the whole of this arch is illuminated, Saturn is 'full'; at other times he presents all the phases shown by our moon, and the arch of light is correspondingly shortened. Saturn 'full' and in the zenith, with the ring-system dependent on either side of his disc, must be a glorious spectacle as seen from certain regions of his innermost satellite. The display would diminish in grandeur, though not perhaps in interest, as seen from satellites farther and farther away. But the inhabitants of the outermost satellite of all have the privilege of seeing the Saturnian ring-system opened out much more fully than as seen from the other satellites, since the path of this moon is inclined some 15 degrees to the plane of the ring.

Of the satellites of Uranus and Neptune little can be said, because so little is known either respecting these orbs themselves or their primaries. It seems clear that Sir William Herschel was mistaken as respects four of the satellites of Uranus he supposed he had detected. Uranus has but four known satellites and Neptune only one. Possibly other Uranian satellites may one day be discovered, and Neptune also may possibly have several satellites circling around him. But only the five bodies above-mentioned are at present known.

CHAPTER IX.

METEORS AND COMETS: THEIR OFFICE IN THE SOLAR SYSTEM.

THERE are few more interesting chapters in the history of astronomy than that which deals with the gradual introduction of meteors into an important position in the economy of the solar system. Regarded for a long time as simply atmospheric phenomena (though many ancient philosophers held another opinion), it has only been after a long and persistent series of researches that they have come at length to be regarded in their true light. But though the history of those researches is not only full of interest, but highly instructive and encouraging, this is not the place for entering at length into its details. I must present facts and conclusions, rather than the narrative of observations or calculations by which those facts and conclusions have been established. Nay, it would seem at first sight as though even the nature of meteors could have very little to do with the subject of this treatise, since we cannot suppose these small bodies to be inhabited worlds. It will be found, however, that, though this is certainly true, there are reasons for believing that

meteors are associated in a very intimate manner with the general relations of the family of worlds forming the solar system.

Under the head 'Meteors' I include all those objects which reach the earth's atmosphere from without, whether they actually make their way to her surface unbroken, like the aërolites; or explode into small fragments, as bolides and fireballs have been observed to do; or are apparently consumed in traversing the upper regions of the air, as happens with shooting or falling stars. All these objects, we now know, represent in reality bodies of greater or less size, which, before their encounter with the earth, were travelling around the sun in orbits of greater or less eccentricity. The larger masses, though they must be very numerous (or our earth would not once in many ages encounter any of them), are yet relatively few in number as compared with fireballs, and still more so in comparison with shooting stars. It has been calculated, indeed, that these last are so numerous that the earth, in passing through a region of space equal to her own dimensions, must encounter no less than 13,000 of them; while of yet smaller bodies, whose passage through our air would only be recognisable by telescopic aid, she is supposed to encounter as many as 40,000 within a similar space. Without laying great stress on these calculations, we may yet feel quite sure that the earth must encounter enormous numbers of these bodies, from the mere fact that, though at any fixed station but a minute slice (so to speak) of the earth's atmosphere is within view, and

even but a portion only of that slice visible to a single observer, six or seven falling stars on the average may be seen during each hour of the night.

It will be seen, then, that a problem of the utmost importance was involved in the question whether these bodies came from the interplanetary spaces, or from the region of space over which the earth's own attractive energies prevail. Now that we know the former view to be the true one, we recognise the fact that, though each meteor may be individually insignificant, the meteors of the solar system, looked on as a single family, form a highly interesting and important portion of the sun's domain.

But now a yet more significant relation has to be considered. Regarding meteors as planetary bodies, they might yet be relatively unimportant, if we had any reason to believe that they form a sort of zone or belt near the earth's orbit, resembling in a sense the asteroidal zone, only composed of far smaller constituent bodies. We could not *then* infer from the number of meteors encountered in a given time by the earth, the largeness of the total number of these bodies; for it might well be that this zone had no counterpart, either in the outer part of the planetary system or within the orbit of the earth. What has actually been discovered, however, respecting the paths along which the meteoric bodies have reached the earth, immensely enhances the importance of these objects.

It has been proved, on evidence perfectly incontestable, that two well-marked meteoric systems travel in

orbits of enormous eccentricity. The August meteors travel on a path so eccentric that in the neighbourhood of the earth's orbit it may be regarded as almost parabolic in figure. That it is not absolutely parabolic is shown, of course, by the fact that a period has been assigned to the revolution of the members of the zone. No observations have indeed been made by which astronomers could determine the orbit of these meteors, since for this purpose an exact determination of the velocity with which they enter the earth's atmosphere would be requisite, while the observations actually made to determine their velocity are confessedly inexact. But an association, altogether too close to be regarded as accidental, has been discovered between their orbit and that of a bright comet which appeared in 1862, and this, combined with what has since been established respecting the relations between comets and meteors, enables astronomers to adopt quite confidently the orbit of the comet as that of the meteoric system. Now a period of 145 years implies, according to Kepler's law, an orbit having a mean distance nearly equal to that of Neptune. And since the orbit is so eccentric as to bring these bodies close to the earth when they are near perihelion, it follows that their aphelion distance must exceed their mean distance in the same degree. Hence the aphelion point of the August meteors must lie nearly twice as far away from us as the orbit of Neptune.

The November meteors have been shown in like manner to travel in a period of 33¼ years around the

sun, the aphelion of their orbit lying far beyond the path of Uranus.

So far, then, as we can judge from the only two meteoric systems whose orbits can be said to have been satisfactorily determined (though there are many other systems which have been associated with known comets), we are led to the conclusion that the meteoric orbits are for the most part eccentric. We know, further, that they are inclined in all directions to the plane in which the earth travels, because we see that their constituent bodies fall upon the earth in directions which shows no tendency to near coincidence with the ecliptic.

These two circumstances are full of meaning. If the meteors travelled in nearly circular orbits at a mean distance nearly equal to the earth's mean distance from the sun, then the earth would be certain to encounter meteors in the course of her orbital motion round the sun. Again, if the meteors travelled in eccentric orbits, whose perihelia lay within the earth's orbit, and if these orbits all lay in or near the plane of the earth's path, the earth could not fail to encounter meteors as she travelled round the sun. But under the actual circumstances—the mean distances of the meteoric orbits being in no way associated with the earth's mean distance, and the inclination of these orbits to the ecliptic not being in any way limited—the two questions are at once suggested, (1) What is the *à priori* chance that the earth would encounter the members of any meteoric system taken at random? and, (2) If this chance

be small, what is the conclusion to be drawn from the fact that the earth encounters meteors belonging to many systems?—the number already recognised being nearly sixty. Assigning elements at random to a meteor system, we see that, unless the resulting orbit actually coincides with the plane of the ecliptic (a relation which would not happen in a million trials), the orbit will intersect that plane in two points, lying on a straight line through the sun. And for the earth to encounter members of the meteoric system, it is requisite that one or other of these two points shall lie close to the earth's orbit. But these points may have any position whatever in the plane of the ecliptic, and the chance that one of them has the requisite position may be regarded as indefinitely small. It follows, then, that the *à priori* chance of the earth's encountering the members of a meteoric system is indefinitely small; and hence we conclude that the number of meteoric systems of which she passes wholly clear is indefinitely great, in comparison with the number whose members she encounters. But she actually encounters meteors belonging to more than four hundred systems. Hence the total number of meteoric systems belonging to the planetary scheme must be an indefinitely large number of hundreds—or in other words, it must be enormously beyond our powers of conception.

This being so, it behoves us to inquire, first of all, what extent we must assign to individual meteoric systems, and how densely we may suppose meteoric masses to be strewn along each system; and secondly,

what may be the nature, quality, and substance of these meteoric masses. For we begin to see that we are in the presence of relations which may—or I should rather say which must—affect most importantly the economy of the solar system.

Now we have seen something already of the longitudinal extent of meteoric systems, since that extent corresponds to the circumference of meteoric orbits, and we have seen that these orbits have enormous dimensions. We may indeed suppose that in some cases the whole extent of an orbit is not occupied by meteoric masses at any one instant: but even when, as in the case of the November meteors, the annual displays wax and wane in splendour, there is no absolute cessation in the occurrence of star-falls on the date corresponding to such a system. And taking full account even of the marked diminution which actually occurs we are yet compelled to assign an enormous longitudinal extent to that portion of the system which has been poetically termed 'the gem of the meteor-ring.' For example, in the November meteor system, this portion of the ring cannot be less than 1,000,000,000 miles in length. As to the width of a meteor system—that is, its extent in a direction measured in the plane of its orbit—we have no satisfactory information, because a meteor system may extend enormously on either side of the point through which the earth's orbit intersects it, and yet no trace of that extension be recognised by observers on the earth. Still we may conclude that this dimension lies in extent somewhere between

the longitudinal extension of the system and the depth of the meteor zone—that is, the length of a line taken through it, square to the plane in which it lies. Now of this last dimension we can form a tolerably accurate estimate in many instances. We know that so long as meteors belonging to any system are flashing into view, our earth is still plunging through the system; and if we know the position of the system, we can determine its depth in this way, just as we could determine the breadth of a range of hills if we noticed the time occupied by a train, travelling with known velocity, in passing through a tunnel which traversed the range of hills in a known direction. Judged in this way, the depth of the November meteor zone would seem to be 100,000 miles in the part traversed by the earth in 1866, about 60,000 miles in the part traversed in 1867, and considerably greater (though the zone was more sparsely strewn with meteors) where the earth crossed the system in 1868, 1869, and 1870.

Now as regards the density with which meteors are strewn in any known system, I must remark on a mistake which has been sometimes made. It has not been thought necessary to consider the velocity with which the meteors themselves travel, as well as the earth's velocity, in order to determine from the average interval of time separating the appearance of successive meteors the average distance separating neighbouring meteors from each other. This, however, is an erroneous mode of dealing with the problem. We must consider the meteoric velocity, since the meteoric

motions manifestly tend to affect the total number of encounters.[1] Let us apply this consideration to enable us to form a rough estimate of the number of bodies in the richer part of the November meteor system. We may fairly assume that, taking the average of the four displays of the years 1866–69, the earth encountered more than one meteor per minute as she swept onwards through the system; or, conveniently for our purpose, that an average distance of 1,000 miles separates meteor from meteor throughout the 'gem of the ring.' Now the length of the great cluster is at least 1,000,000,000 miles, its thickness may be fairly assumed as averaging 100,000 miles, and its width can hardly be less than ten times its thickness, since the forces acting on the system tend much more largely to affect its width than its thickness. Thus, with the assumed average of distance (1,000 miles), we find that the cluster cannot contain less than (1,000,000 × 100 × 1,000) or one hundred thousand million meteors!

Prof. Alexander Herschel, from observations of the amount of light given out by these bodies, and a calculation founded on the velocity with which they penetrate our atmosphere, has come to the conclusion

[1] Obviously the total number of meteors encountered during the earth's passage through a meteor stream will be the number contained in a cylindrical space having a cross-section equal to the earth's, and traversing the meteor stream from side to side. The motion of the meteors will affect the particular set of meteors actually found within this space as the earth traverses it, and will also affect their number, assuming a general uniformity of meteoric distribution

that they must, for the most part, be very small, rarely, perhaps, exceeding a few ounces in weight. We shall certainly not exaggerate their weight if we assign one-hundredth part of an ounce to each. We thus obtain for the weight of the whole cluster one thousand millions of ounces, or about 28,000 tons. The actual weight of the November meteor system cannot however but enormously exceed this amount; and therefore we recognise how erroneous that opinion is which an eminent astronomer has expressed, who asserted that the united weight of all the bodies other than planets in the solar system must be estimated rather by pounds than by tons. We have certainly no reason for thinking that the November system, though one of the most important encountered by the earth, is exceptionally important in the solar system. On the contrary, we have every reason which the laws of probability can afford us for believing that there must be millions of systems equally or more extensive. And further, the fall of enormous masses, many tons sometimes in weight, upon the earth, would point to the conclusion that the members of the November system are exceptionally insignificant as regards their individual dimensions. So that we seem forced to the conclusion that the aggregate weight of the various meteoric systems circulating around the sun must be estimated by billions of tons rather than by any of our ordinary units.

I have already referred to the relation which has been detected between comets and meteor systems.

Perplexing as the relation appears, it has been established on evidence which cannot reasonably be disputed. It carries with it results of extreme interest and importance.

I do not propose here to enter into any consideration of those enormously difficult questions which are suggested by the study of cometic phenomena. That they will before very long receive their solution I confidently believe; but in the present state of our knowledge it would indeed be hazardous to speculate as to what that solution may be. I may remark, in passing, that while I recognise in recently promulgated theories on the subject the indication of a highly suggestive and promising line of research, I cannot but feel that cometic phenomena are far too complicated to be directly accounted for in any of the ways pointed out of late by physicists. Some of the more obvious, and, I may add, the more generally known phenomena, do indeed appear to receive a solution when examined under the light of recent researches, but numbers of others not only remain unaccounted for, but stand apparently altogether opposed to suggested theories.

For my present purpose, however, the facts to be principally noticed are in a sense independent of any views which may be formed respecting the nature of comets. We know that the dimensions of these objects are in many cases enormous. We know, further, that there must be many thousands of comets remaining undiscovered, for each that our astronomers have

band between the Two Fishes,[1] indicate how clearly the ancients traced certain well-marked star-streams. The moderns have traced the extension of some of these streams in the constellations Grus, Hydra, Reticulum, &c. into the near neighbourhood of the southern pole. Now the nebulæ in the southern heavens exhibit a well-marked tendency to aggregate into streams. So that, in this mere resemblance between the general characteristics of the stellar and nebular systems in the southern heavens, we have a somewhat remarkable evidence of association. But when we consider the disposition of the two sets of streams—the stellar and the nebular—this evidence is very much strengthened. There is found to be a well-marked correspondence between the nebular and stellar streams, not merely as respects general position, but even in minute details—the nebular streams following the windings of the stellar ones. Such a relation would be very remarkable, even were it observed but in a single instance. Since, however, all the well-marked star-streams in the southern heavens are associated with well-marked nebular streams, no doubt can remain that the relation is not a mere coincidence, but indicates a real association between the nebular and stellar systems.

But yet more striking evidence remains to be considered.

[1] Though Pisces is not a southern constellation, yet it is south of the galactic circle, to which I am for the moment referring the constellations.

the solar system, but upon asteroids and satellites—nay, are even streaming in among the minute bodies composing the rings of Saturn. These encounters cannot be wholly without result, and it is quite conceivable that most injurious consequences might ensue to the inhabitants of all the worlds in the solar system if the continual supply of meteoric matter were importantly diminished.

Now, if meteoric masses fall continually upon the planets, such masses must fall in numbers inconceivably greater upon the sun; and it is here, unless I mistake, that the great purpose of the meteoric systems becomes apparent.

Let us clearly recognise, however, why and how the sun must be assaulted by a continual inrush of meteoric bodies. We have seen how enormous must be the number of these bodies; we know how swiftly they travel, and on what eccentric orbits; but we must go farther before we can prove that they fall upon the sun. For example, the November meteors are enormous in number, and travel with enormous velocity in a very eccentric orbit, but they do not approach the sun within a distance of nearly 90,000,000 miles. Nor, indeed, can any known meteoric system pour a steady hail of meteors, so to speak, upon the sun; for he is the ruling centre of every meteoric system, and therefore under ordinary circumstances the meteoric orbits must pass around him, and not in such directions as to intersect his substance.

But it is to be remembered that meteors must be

infinitely more crowded in the neighbourhood of the sun than at a distance from him. An indefinitely large number of meteoric orbits must absolutely intersect in the immediate neighbourhood of the sun; and collisions must be continually taking place as countless thousands of meteoric flights rush towards and past and then away from their perihelia. Where these perihelia lie close to the sun the velocity with which the meteors travel must exceed 200 miles per second, and therefore the collision even of two minute meteors must result in the generation of an enormous amount of light and heat. But that is not all. Amongst the collisions thus continually taking place in the sun's neighbourhood there must be a considerable proportion in which the two bodies are brought momentarily almost to rest by the shock. In such cases the combined mass of the two meteors would fall directly upon the sun, a fresh supply of light and heat being generated as they were brought again to rest upon his surface.

Whether in the continual collisions of meteors amongst themselves, and in their precipitation upon the sun's surface, we have a sufficient explanation of the seemingly exhaustless emission of light and heat from the sun, I should not care positively to assert. Sir W. Thomson, who was one of the first to adopt this view, has now abandoned it; though it is worthy of remark that the strongest evidence in its favour has been obtained since he withdrew his support from it, or at least admitted that the downfall of

meteors on the sun's surface is not *alone* sufficient to account for the solar light and heat. But so far as I can judge, there is no flaw in the evidence I have adduced from the laws of probability applied to recent discoveries; and that we are bound to accept as a legitimate conclusion from that evidence the theory that at least a proportion of the sun's heat is supplied from the meteoric streams which circulate in countless millions around him. It can no longer be believed, however, without adopting unreasonable assumptions, that the whole of that enormous supply of light and heat which the sun emits on every side is derived from the meteoric streams belonging to the solar system or drawn in from surrounding space, as the sun, attended by his family of planets, sweeps onwards amid the stellar groups.

If this view were correct, then the meteor systems would constitute indeed a most important part of the sun's domain. They might be said almost to share with the sun a title to be regarded as the source of all the forms of force which exist throughout the solar system. If in the energies of living creatures on earth, in the forces derived from the fuel that propels our engines, or in the power of winds and storms, we trace the action of the ruling centre of the solar system, we might trace back the chain of causation yet one link farther, and see in the sun's emission of light and heat the result of forces inherent in the meteoric systems which circle around him.

But we must not forget one most important consideration, which would make the sun (as might be anticipated) again the chief source of all the forms of force existing within his system. The motions of the meteoric masses are almost wholly due to the sun's attraction; and therefore, in so far as those motions are to be regarded as a means of renewing the solar heat, we must regard the sun's attractive energy as the source whence his heat and all the other forms of force which he exerts are in reality derived.

Yet one step farther. The sun's attractive energies might be increased a thousand-fold, and yet not avail to supply the various forms of force which are required by his dependent worlds, were there no external material on which those energies could act in such sort as to lead to the continual inrush of matter upon the solar surface. Nor would it suffice if such materials, even in enormous quantities, existed *close* to the sun. It is the distance from which that material is dragged towards the sun which gives that orb the power of imparting those tremendous velocities to which the collisions of the meteoric bodies owe their real effectiveness. We thus find in *distance*, in the simple element of *scale*, the true source of the various forms of force which are continually exerted throughout the solar system. The sun surrounded by millions on millions of meteoric masses close at hand would be powerless; but placed as ruler over a space far wider than the sphere circled by Neptune's orbit, amidst which space those countless millions of meteors are

distributed, he becomes forthwith the centre of a thousand forms of energy, gathered by him continually from the systems of meteors circling around him, and distributed by him abundantly and without ceasing to his dependent worlds.[1]

It will not fail to be noticed by the thoughtful reader that, adopting this view of the relation in which meteoric and cometic systems stand with respect to the sun, it seems necessary that we should regard those planets which I have endeavoured to raise to the dignity of secondary suns, as subordinate centres of attraction, around which countless thousands of meteoric systems may be supposed to circle. Have we any evidence pointing to such a conclusion?

Now there can be no doubt that if Jupiter, the nearest of these secondary suns, did so act upon a passing comet as to compel that body to circle in future around *him*, instead of pursuing its course around the sun, we could not in any way become cognisant of the event unless the comet were an exceptionally large one. I conceive, however, that such

[1] Just as this work (the first edition) was about to be placed in the printer's hands I received from Professor Kirkwood, of America, one of his valuable contributions to the history of the solar system. In it he points to the evidence we have that the sun, as he speeds onwards through space, passes through regions in which cometic and meteoric materials are now richly, now sparsely strewn, and gathers in accordingly new stores of force of greater or less amount. The bearing of the views of this acute and soundly reasoning astronomer (the Kepler of our day), not only on the theories dealt with in the above chapter, but on those considered in the chapters which follow, will be seen at once.

an event, though undoubtedly possible,[1] must be so uncommon that the number of cometic systems thus forced to own Jupiter as their centre of attraction must be relatively few. But in another way the planet does exhibit his power as a comet-ruler, making comets recognise him as a sort of subordinate master, the sun being their primary ruler. When comets coming from outer space pass near enough to Jupiter, he sways them so markedly from the orbit they are pursuing that the scene of encounter becomes the aphelion of their orbit, or nearly so. Thence they pass on their new orbit to their perihelion, returning again presently to the scene of their encounter with Jupiter, and so revolving in an orbit having its aphelion close by the orbit of Jupiter, until haply the giant is again near the scene of encounter at the

[1] It is necessarily possible in the case of any planet, but must in many cases be highly improbable. For example, astronomers sometimes assert that meteoric masses passing near the earth might become satellites of hers; but in reality this is a very unlikely event, because the maximum velocity which a body travelling under the earth's influence can have (that is, the velocity acquired by a body travelling from infinity to a perigee close to the earth) is less than the velocity with which a body circling on any orbit round the sun would move when at the earth's distance from him, unless its orbit were very eccentric and the aphelion close by the earth's orbit. Bodies travelling from outer space towards the sun cannot by any possibility become satellites of the earth, because they would always have a velocity greater than that which her attraction can master. Even in the rare event of their grazing her atmosphere, and so losing a large share of their velocity, they could not become permanent satellites of hers, because, returning to the scene of encounter, they would lose yet a larger share of their velocity, and so must be brought, and that soon, to her surface.

moment when the comet comes back to it. In this case a fresh struggle takes place, the overmastering attraction of the planet necessarily prevailing, and the comet being often dismissed on a new orbit, whose perihelion, instead of its aphelion, lies close by the orbit of Jupiter.

Now we know that such events as these must be of frequent occurrence as Jupiter sweeps swiftly round on his orbit. For we recognise several comets which have evidently been compelled by Jupiter to take up such orbits as I have spoken of—a family of comets, in fact, including Encke's, Faye's, and Brorsen's, Winnecke's short-period comet, and several others. We judge further, from the laws of probability, that for each discovered comet of this family there must be thousands which have escaped detection. So that around the orbit of Jupiter (if not around Jupiter himself) there cling the aphelia of myriads of cometic orbits whose perihelia lie at all conceivable distances from the sun less than the distance of Jupiter.

Saturn also has his family of comets; so also have Uranus and Neptune. The comet associated with the November meteors belongs indeed to the Uranian comet-family, and the epoch (126 A.D.) has even been pointed out when this comet may have fallen under the dominion (subject always to the sun's superior control) of that distant planet.

And here I may refer to a view which I have long entertained respecting the purposes which meteoric

and cometic systems have fulfilled in the past history of the solar system.[1] We know that the materials composing meteors, and we conclude, therefore, that those composing comets, do not differ from those which constitute the earth and sun, and presumably the planets also. Therefore under the continual rain of meteoric matter it may be said that the earth, sun, and planets are *growing*. Now the idea obviously suggests itself that the whole growth of the solar system from its primal condition to its present state may have been due to processes resembling those which we now see taking place within its bounds. It is of course obvious that if this be the case, the number of meteoric and cometic systems must have been enormously greater originally than it is at present. Countless millions of meteoric systems, travelling in orbits of every degree of eccentricity and inclination, travelling also in all conceivable directions around the centre of gravity of the whole, would go to the making up of each individual planet. A marked tendency to aggregate around one definite plane, and to move in directions which, referred to that plane, corresponded to the present direction of planetary motion, would

[1] Since the present chapter was written, I find that the hypothesis here put forward has in a general way been touched on by more than one astronomer and physicist. I believe, however, that here, for the first time, it has been associated with the chief features of the solar system. It was suggested in note B (Appendix) to my treatise on Saturn. But as a matter of fact, when that note was written, as also when those passages were published in which the same hypothesis is dealt with by other authors, decisive evidence in favour of the theory was wanting.

suffice to account for the present state of things. The effect of multiplied collisions would necessarily be to eliminate orbits of exaggerated eccentricity, and to form systems travelling nearly in the mean plane of the aggregate motions, and with a direct motion. Further, where collisions were most numerous, there would be found not only the most circular resulting orbits, not only the greatest approach to exact coincidence of such orbits with the mean plane of the whole system, but the bodies formed out of the resulting systems would there exhibit rotations coinciding most nearly with the mean plane of the entire system.[1]

It seems to me that not only has this general view of the mode in which our system has reached its present state a greater support from what is now actually going on than the nebular hypothesis of Laplace, but that it serves to account in a far more satisfactory manner for the principal peculiarities of the solar system. I might indeed go further and say that where these peculiarities seem to oppose themselves to Laplace's theory, they give support to that which I have put forward.[2]

[1] This conclusion depends on a well-known law of probability. It may be thus illustrated :—If we have in a bag a million white and a million black balls, and take out at random a number of balls, then the larger that number, the more nearly (in all probability) will the number of black and white balls included in it approach to a ratio of equality.

[2] It is scarcely necessary to remark that as regards at least the larger members of the solar system—including the four primary planets within the zone of asteroids—the nebulous condition inferred by Laplace would necessarily result from the processes above suggested; so that, in a sense, the above account may be supposed

For example, what is there in the nebular hypothesis which affords even a general explanation of the strange varieties of size observed in the planetary system? How can that hypothesis be reconciled with the remarkable variations of inclination observed among the planets, or with the retrograde and almost perpendicular motion of the satellites of Uranus? Nor, again, is the hypothesis consistent with the observed peculiarities of motion of those meteoric systems which we must now regard as regular members of the solar system.

Now, according to the hypothesis I have put forward above, a general explanation of all these matters is as once suggested. Let us consider:—

In the neighbourhood of the great central aggregation which would undoubtedly result from the motions of such meteoric systems as I have considered, all the motions would be very rapid. They would, in fact, resemble the motions now actually observed in the sun's neighbourhood. Here, therefore, subordinate aggregations would form with difficulty, since they would have small power of overruling meteoric systems rushing with so great a velocity past them. In the sun's immediate neighbourhood, then, we should expect to find relatively small planets; and we do accordingly find that Mercury, nearest to him, is the smallest of the planets, Venus larger, and the earth (yet further away) not only larger than Venus, but adorned with an attendant satellite.

to describe a state of things antecedent to the nebulous condition of the planets and sun, as conceived by Laplace. See also note B to my treatise on Saturn.

Now, at a much greater distance from the sun the meteoric motions would be so much less that here, supposing only a suitable mean density of aggregation, it would be possible for much larger subordinate centres of aggregation to form. These centres would increase in importance as they swept round the central aggregation, continually gathering fresh recruits. Indeed, though, *as now*, they would not be able to prevent the major part of the materials rushing from outer space towards the sun from aggregating round *him*, they would still gather in no inconsiderable portion of those materials. Where the largest portion would be gathered would depend on the way in which (taking a general view of the system) the quantity of material increased towards the neighbourhood of the centre. For clearly, while distance from the sun would increase the facility with which materials would be gathered in—since the sun's influence would diminish with distance it would also affect the quantity of material available—since, from a very early period, the system must have begun to show an appearance resembling that now presented by the zodiacal light—that is, a general increase of density towards the centre.

Assuming that the region of maximum aggregation was that where the influence of the ruling centre first became so far diminished with distance as to render the formation of a great subordinate aggregation possible, we should have the innermost of the outer series of planets also the most bulky; and next within the orbit

of that giant planet we should find a relatively barren space, cleared of material not only by the sun's still powerful influence, but also by the influence of this first important subordinate aggregation. The initial assumption is, in itself, at least not improbable, and having once admitted it, we find an explanation of the giant mass of Jupiter, of the comparative poverty of material just within the orbit of Jupiter, and hence of the condition of the asteroidal zone, and of the smallness of the planet Mars next within that zone—though this planet far outweighs (according to Leverrier's estimate) the united mass of all the asteroids. Beyond the orbit of Jupiter, we should expect (after passing an enormously wide space, bare of worlds) to find still a great abundance of material, and an even greater facility in the aggregation of that material. Thus the existence of the planet Saturn, next in importance to Jupiter, and surpassing him in the complexity of his attendant system, is accounted for; yet farther away, we look for and find still an abundance of material, and that material somewhat more uniformly strewn, while the sun's small influence is indicated by the existence of satellites, of which doubtless many more will one day be discovered by astronomers.

As to the rotations of the various members of the solar system we find some account, necessarily not exact, given by this theory. I have mentioned above the results to be looked for; those observed are closely accordant with that view. Thus the sun, the largest member of the system, and specially pre-eminent

within its inner division, has its equator inclined but about seven degrees to the mean plane of the system. Mars, the least member of this system, has an inclination of no less than twenty-eight degrees; the larger earth an inclination of but twenty-three degrees. The inclinations of Venus and Mercury are undetermined; they may be expected to be large, not merely on account of the smallness of these bodies, but on account of their proximity to the sun. Of the outer division of the system, Jupiter, the largest, has an inclination of little more than three degrees; Saturn has a very considerable inclination (more than twenty-six degrees); Uranus has an inclination which may be described as actually greater than ninety degrees, since he rotates *backwards* with his equator inclined seventy-six degrees to the ecliptic. And lastly, if the observations hitherto made on Neptune's satellites are to be trusted, this planet probably rotates in a retrograde manner, his equator being inclined some twenty-six degrees to the horizon; so that, to render the comparison between his rotation and that of the other members of the solar system complete, he may be said to rotate in a direct manner with his equator inclined some 154 degrees to the ecliptic.

The great inclination and eccentricity of many of the asteroidal orbits is also accounted for more satisfactorily by this theory than by the nebular hypothesis. There is perhaps no absolute incorrectness in the assertion that the smallness of the asteroids explains (on the ordinary view of their origin) the relatively irregular

nature of their motions. Their minuteness doubtless brings them (when long intervals of time are considered) more under the disturbing influence of Jupiter than a single massive planet at the same distance from the sun would be.[1] But the attraction of Jupiter can scarcely have been sufficient to cause the asteroids to depart so widely as they do from the ecliptic, since his path lies quite close to the ecliptic, and even nearer to the mean plane of the solar system. Bodies formed as the asteroids are supposed to have been, according to the hypothesis I have suggested, would necessarily exhibit a much greater variety of motion than would be recognised in the case of the larger planets.

[1] The most eminent astronomer of our day indicated in a private communication an objection to this sentence (originally written without the parenthetical passage), founded on the fact that the disturbance by Jupiter of a single planet as large as the earth (or even Neptune) travelling on the orbit of one of the asteroids, would be precisely the same as the disturbance of the asteroid, or even of a much minuter body—as a meteor or a peppercorn. This is just; but the contrary was not meant to be implied by the above sentence as it originally stood. It was to the influence of Jupiter in long cyclic periods, during which the reflex actions due to the changes in Jupiter's own orbit through the action of the perturbed body came into play, that I referred. In the case of two planets of nearly equal mass—or of masses comparable in magnitude—there is an interchange of eccentricities and inclinations, and these can never become very large for either planet. It is different, however, when one of the bodies is exceedingly minute, for then the orbit of the larger changes so slowly that perturbing effects are renewed again and again, during a very long cycle, so that before the reverse processes begin to act a very considerable eccentricity or a very considerable inclination may be given to the smaller body. That this is so is shown by the much wider range within which the eccentricities and inclinations of the smaller planets of the solar system are known to oscillate in long intervals of time.

Another point in which, as I conceive, my hypothesis is more satisfactory than the nebular one consists in the fact that it suggests an explanation of the peculiarities observed in the planetary periods. Professor Kirkwood's researches into the various relations of commensurability presented among the periods of planets and satellites, and the known effects of commensurability in encouraging the accumulation of planetary perturbations, will at once suggest to the mathematical reader the way in which a system forming in such a manner as I have imagined might be expected to exhibit the presence of law as regards distances and periods. There is nothing in the nebular hypothesis which encourages the belief that a system framed as Laplace conceived the solar system to be, would exhibit any such laws as are found within the planetary scheme.

The hypothesis I have put forward also gets rid of what has always seemed to me the great difficulty of the nebular hypothesis. According to the views of Laplace, Neptune must have been formed millions of ages before Uranus, Uranus as long before Saturn, Saturn as long before Jupiter, and so on. Now we know that the appearance of those primary members of the solar system which we are best able to study does not indicate any such enormous disproportion in the ages of the planets, even if it does not indicate that the planets were formed nearly at the same era. According to my hypothesis, the various processes of aggregation would go on simultaneously

(just as the influences which Jupiter *now* exerts on comets act simultaneously with the more powerful influences exerted by the sun); and though the various orbs formed by those processes would not necessarily be completed simultaneously, there would be no such enormous disproportion in their age as is necessary according to the theory of Laplace.

Yet another strong point in favour of this hypothesis resides in the circumstance that we now have every reason to believe that all the planets are constituted of the same elements. When it was thought that Jupiter might be a watery globe, for instance, there was some evidence in favour of Laplace's theory. But we now know that Jupiter is not constituted differently, in all probability, from the earth and sun, as according to Laplace's theory he must have been. Since, then, we know that meteors contain the same elements which exist in the constitution of sun and planets, we have here a very strong argument in favour of the view that they have played the important part I have assigned to them in the formation of the solar system.

But after all, the strongest evidence in favour of the hypothesis I have suggested consists in the fact that the processes by means of which I conceive the solar system to have been formed are undoubtedly going on before our eyes. There may be little, indeed, in the downfall of meteoric showers to suggest the idea of world-formation or sun-formation; little in the present aspect of the zodiacal light or of the solar corona to present to the mind's eye a picture of that vaster

agglomeration of meteoric and cometic systems, all speeding with inconceivable velocities on their interlacing orbits, which I imagine to have been the embryon of the solar scheme. But sun and planets *are* growing, however slowly, as the meteoric hail falls continuously upon them; the zodiacal light and the solar corona *are* doubtless due to the existence of meteoric systems, resembling (however relatively insignificant) those which I have pictured as the materials of the planetary scheme. In the Saturnian rings, also, which have been proved by the researches of Maxwell and others to consist of multitudes of discrete bodies, we have evidence of the same sort in the case of a subordinate centre of aggregation. So that we have a form of evidence, which was wanting in the case of the nebular hypothesis, in favour of this other hypothesis, by which, as in Laplace's, the present state of the solar system is regarded as the result of a process of development, and not of special creative fiats.

CHAPTER X.

OTHER SUNS THAN OURS.

We are now to venture into regions where we shall no longer have clear lights to guide us. Tremendous as are the dimensions of the solar system, the widest sweep of the planetary orbits sinks into insignificance compared with the distances which separate from us even the nearest of the fixed stars. From beyond depths which the human mind is utterly unable to conceive there come to us the rays of light which myriads of those orbs are pouring forth, and it is from the lessons taught us by these light-rays that we are to form our ideas concerning the nature of the orbs which emit them. Very carefully and cautiously must we proceed, if we would avoid being led into vain imaginings. It will but mislead us to pass a single step beyond the path which is dimly lighted for us, and yet that path is so narrow and so obstructed with difficulties that we find ourselves continually tempted to leave it, and to venture forward on the alluring and easy paths which speculation opens out on every hand around us.

And yet we may well remain content to listen only

to the teachings of known facts. Even so restraining ourselves, we have in reality a wide and noble domain to explore. Facts which seem severally unimportant, are found, when considered as parts of a grand whole, to indicate relations so impressive and so interesting that the revelations of the telescope within the solar system are apt to seem commonplace beside them. We have, in fact, no longer to consider the structure of a system—the architecture of the universe is our theme.

Let us examine carefully the evidence which science has gathered together for us, endeavouring at each step to gain the full amount of knowledge the several facts involve, while at the same time cautiously refraining from any attempt to overstep the bounds indicated by our evidence.

In the first place let us consider what may be learned from the analogy of the solar system. The study is an inviting one, since the discoveries on which we are to found our views have been made so recently that the subject has all the charm of novelty and freshness, while it involves the consideration of the soundest and most instructive mode of pursuing our researches.

We have seen in the solar system a variety and complexity of structure, such as, half a century ago, few astronomers would have thought of ascribing to it. When Sir William Herschel began that noble series of researches amid the sidereal depths by which his name has been rendered illustrious, he saw in the solar system a scheme very different indeed from that

which is presented to our contemplation. He beheld a vast central body, surrounded by a limited number of orbs, some of which are the centres of subordinate schemes of greater or less extent. When we have added the ring of Saturn as the only formation differing from planets and satellites in character, and the comets, few and far between, which seemed rather accidental tributaries of the sun than regular members of his family, we have considered all the features which the solar system, as known in Sir William Herschel's day, presented to the contemplation of astronomers.

With us it is very different. We see that there exists within the solar system a variety of size and structure, of motion, arrangement, and aggregation, which is already inconceivable, and yet doubtless but faintly shadows forth the real complexity and richness of the scheme swayed by our sun. Perhaps it is in considering the solar system in the particular light in which, in this treatise, I have had occasion to present it, that this wonderful variety of conformation is made most strikingly apparent. But, apart from all speculative theories, there can be no doubt that the solar system presents to us a subject of study amazing in itself, but most amazing when we regard it as supplying the analogies which are to guide us in forming our views respecting the sidereal system. Besides the family of planets circling round the sun, besides the system of dependent orbs which circle round the planets, we see a zone in which independent planets circle by hundreds, perhaps even by myriads, around

the solar orb; we see the ring of Saturn composed of thousands of tiny bodies; we see the meteoric systems in countless hosts; we see the comets of our scheme in millions on millions; and less certainly, but still not indistinctly, we recognise the existence of a multitude of new and hitherto unsuspected forms of matter within the circle of our sun's attraction.

What opinion then are we to form—even here, at the very outset of our inquiry—respecting the sidereal scheme of which our sun forms but an unit? Surely it would be to lose sight of the significant lesson taught us by the solar system, it would be to forget how sure and safe a guide the greatest of modern astronomers found in the teachings of analogy, to adopt the same view now which that great astronomer adopted a century ago. If, viewing the solar system as consisting of discrete orbs, comparable one with another in size, and distributed with a certain uniformity around their ruling centre, Sir William Herschel held that the sidereal scheme presented somewhat similar relations, surely *we*, who know certainly that the solar system is constituted so differently must adopt a far different view of the sidereal system also.

Let us remember that there is here—so far as our respect and admiration for Sir William Herschel are concerned—a choice between two courses. Assuming, as indeed is just, that the views of our great men are not rashly to be thrown on one side, we have to choose whether we would rather abandon the views which Sir

William Herschel formed about *facts*, or the views which he formed about *principles*. If we accept his opinion (or rather, after all, his mere suggestion), that the stars are tolerably uniform in magnitude and distribution, we must abandon the analogy of the solar system. If, on the contrary, we accept Sir William Herschel's often expressed opinion that, in theorising about the unknown, there can be no safer guide than the analogy of known facts, we must abandon the view (which seemed to him but probable) that the stars are distributed with tolerable uniformity throughout our galaxy, and are comparable *inter se* in magnitude and splendour.

There can be no doubt which course is preferable. We know certainly that Sir William Herschel was often mistaken, as all men must be, in matters of fact; while we know with equal certainty that he owed the marvellous success with which he theorised to his adoption of the principle that analogy is the chief and the best guide for the student of astronomy.

We are compelled, then, in our very respect and admiration for the greatest astronomer of modern times, to regard the constitution of the sidereal system as, in all probability, very different from what he imagined. We must be prepared to expect an infinite variety of figure, of structure, of motion, and of aggregation throughout the galactic scheme. If some orbs within that scheme seem probably to be suns like our own, we must not be surprised to find others which are probably far larger or far smaller. We may look for

objects differing as much from the suns of the sidereal system as the asteroidal zone differs from Saturn or from Jupiter. So that, if we should recognise evidence of the existence of clusters of minute stars—a whole cluster, perhaps, not equalling in real importance the least of the suns of the system—we may accept that evidence without any scruple suggested by the improbability of the conclusion to which it points. Again, we may expect to find schemes within the sidereal system, differing as much from discrete stars or star-clusters as the rings of Saturn differ from the primary planets or from the asteroidal zone. So that, if we should recognise evidence of the existence of relatively minute clusters, whose components are either so small or so closely aggregated as not to be separately visible even in our most powerful telescopes, this evidence may fairly be accepted as accordant with the only analogy we have for our guidance. Yet once more: we may look for systems differing as much from all ordinary star-clusters as the excentric and far-reaching meteor systems differ from the symmetrical rings of Saturn. So that, if we should find evidence of strange schemes within the sidereal system, schemes presenting strange varieties of figure, with strange complexities of spiral whorls or outlying branches, losing themselves, as it were, in the depths towards which they seem to extend—this also need not surprise us: we need not conclude that *here*, at any rate, we are looking beyond the bounds of the sidereal system, and gazing upon external galaxies; for the analogy we have chosen

for our guidance teaches us that such structures were to be expected within the scheme of which our sun is a component. And finally, if we should find reason to assure ourselves that there are objects in the depths of space whose very substance and constitution are different from those of all other objects within the sidereal system, we need by no means believe that the objects thus singularly constituted belong to or form external systems. For the millions on millions of comets which form part and parcel of the solar system present a precisely analogous difference of structure, as compared with the other members of that system.

Having thus replaced the erroneous analogies to which—through no fault of his own—Sir William Herschel was led to look for guidance, by the more trustworthy analogies which the recent progress of astronomy has afforded for our instruction, we may proceed to consider the direct evidence we have respecting the constitution of our galaxy.

In the first place, let us examine the evidence pointing to the dimensions of the sidereal system.

That the nearest members of the system lie at enormous distances from us is proved by the fact that, as the earth sweeps on her vast orbit round the sun, no appreciable change is observed in the configuration of the star-groups. That a circle having a diameter of more than 185,000,000 of miles should be swept out year by year as the earth traverses her orbit, and yet that the surrounding stars should exhibit no change of place, is at once the most striking and the simplest

evidence we have of the enormous scale on which the sidereal system is constructed. And yet this first obvious fact sinks almost into insignificance when we regard thoughtfully the teaching of modern instrumental astronomy. There might be a real shifting of apparent position which yet the unaided eye would fail to detect, and such a change would indicate distances so enormous that the mind fails altogether to conceive their real significance. But the exact instruments of modern times would exhibit a change of place far more minute than any which the unaided eye could recognise. If a star shifted by so much as the ten-thousandth part of the moon's apparent diameter, modern astronomers could assure themselves of the change of place. And when we remember that in precisely the same proportion that we increase the exactitude of instrumental observation we increase also the significance of the stars' apparent fixity of position, it will be seen at once how astounding is the lesson conveyed by the fact that all but a very few indeed of the stars remain absolutely unaffected—even under the most powerful instrumental examination—by the enormous range of the earth's orbital motion.

We can roughly estimate the distances of the few stars which are thus affected, and thence—on the hypothesis that the intrinsic brilliancy of their light is the same as the sun's—we may form some idea of their dimensions. I shall, however, only apply this process, in detail, to a single case, because my present object is rather to indicate in a general way the scale

on which the sidereal system is constructed than to enter at length on the more exact details which find their place in ordinary treatises on astronomy.

The star Alpha Centauri is one of the brightest in the heavens, Sirius and Canopus alone surpassing it in splendour. But it was not its exceptional brilliancy alone which led astronomers to regard it as likely to afford evidence of an apparent change of place corresponding to the earth's real change of place as she sweeps round her orbit. Of course, the brightest stars are presumably the nearest; but there is another indication of proximity at least equally important. The so-called fixed stars are in reality slowly moving onwards on definite courses—slowly, that is, in appearance, though in reality their motions are doubtless inconceivably rapid. Now these motions, the *proper motions* of the stars, as they are called, are as yet very little understood. We know only that the whole of the galactic system is astir with life, but whither the orbs are severally tending we are not yet able to say. Nor do we know what portion of the stellar motions may be due to the undoubted proper motion of our own sun through space. This, however, may be regarded as certain, that until we know something respecting the laws which regulate the stellar movements we must regard the magnitude of a star's motion as probably an indication of relative proximity. Precisely as a man walking at a great distance from us appears to move much more slowly than one who is walking at the same rate close by, so the apparent rate

of a star's motion is diminished in proportion to the star's distance from us. When, therefore, it was found that the star Alpha Centauri is moving more rapidly than other stars, this fact, combined with the great lustre of the star, led astronomers to suspect that it must be comparatively near to us.

Observations made to determine whether the star shows any sign of an annual change of place corresponding to the earth's annual orbital motion, were rewarded by the detection of a very appreciable displacement. In fact, owing to the motion of the earth, each year, in a nearly circular orbit 185,000,000 miles in diameter, the star Alpha Centauri appears to trace out each year a minute oval path on the celestial sphere, the greater axis of the oval being equal in length to about $\frac{1}{900}$th part of the moon's apparent diameter.[1]

It follows from this, that in round numbers the distance of Alpha Centauri from us is about twenty millions of millions of miles. The distance of the earth from the sun shrinks into insignificance beside this enormous gap. Even Neptune, though circling round the sun at a distance thirty times vaster than that which separates us from that luminary, is yet relatively so much nearer than Alpha Centauri, that a sun filling the whole orbit of Neptune would ap-

[1] It hardly need be mentioned, perhaps, that this motion being superadded to the star's more considerable proper motion, the path which the star seems really to follow is a looped one, the size of each loop being small in comparison with the distance between successive loops.

pear, as seen from that star, but about $\frac{1}{900}$th as large as the sun appears to us.

Now let us consider what dimensions we may assign to Alpha Centauri, on the assumption that the surface of this star emits a light as brilliant as that which proceeds from the photosphere of our own sun. We must not neglect the consideration that the star is double—the companion emitting perhaps about one-sixth as much light as the primary.[1] The distance of Alpha Centauri is equal to about 230,000 times that which separates us from the sun. Therefore, if removed to the star's distance, the sun would shine with only $\frac{1}{52,900,000,000}$th part of his present brilliancy. Now, according to the most careful estimates of the brilliancy of Alpha Centauri, the light we receive from that star is about $\frac{1}{16,930,000,000}$th of that we receive from the sun.[2] It follows, therefore, that the star emits about three times as much light as the sun; and therefore, so far as the emission of light is a criterion of size, the star may be regarded as considerably larger

[1] In the first edition of this work the smaller star was described as emitting about one-sixteenth as much light as the primary; and in a note I remarked that Sir John Herschel, observing the star with his 20-feet reflector, thought the secondary brighter than it is usually considered, but that, for a comparison of this sort, smaller telescopes seemed to me likely to be on the whole more trustworthy. He convinced me that my opinion as to the brightness of the secondary was erroneous. Hence the change in the estimate.

[2] This estimate is founded on Sir John Herschel's comparison between the light of the star and that of the full moon, and Zöllner's comparison between the light of the full moon and that of the sun.

than our own sun. In fact, reducing the total light of the pair by one-seventh, we find that the primary must still emit nearly three times as much light as the sun, and therefore the diameter of the star, as thus estimated, would appear to exceed our sun's in the proportion of about 8 to 5.

We have here, then, clear and decisive evidence in favour of the view that among the fixed stars there are orbs which may be regarded as veritable suns worthy to be the ruling centres of schemes as noble as the solar system. For we know quite certainly that the greater number of the first magnitude stars are very much farther from us than Alpha Centauri, with which, however, they are fairly comparable in brilliancy; so that they may be regarded as for the most part at least equal to that star in size and mass. Sirius and Canopus, indeed, must far surpass Alpha Centauri. The latter, though more than thrice as bright, exhibits no appreciable change of position as the earth circles round the sun. Sirius, which is more than four times as bright as Alpha Centauri, shows an annual change of position which certainly does not exceed one-fourth of that star's. It is therefore four times farther from us than Alpha Centauri, and, did it emit no greater amount of light, would appear to shine with but one-sixteenth of that star's lustre. As in reality it is four times as bright, the real amount of light it emits must exceed that of Alpha Centauri no less than 64 times, and that of our own sun no less than 192 times. So that, judged from this indi-

cation alone, the diameter of Sirius may be held to exceed that of our sun in the proportion of about 14 to 1, an estimate which assigns to Sirius a diameter of nearly 12,000,000 miles, and a volume 2,688 times as large as the sun's.

But on the other hand, still confining our attention to this method of estimating magnitude, we find reason for believing that many of the visible stars must fall far short of our sun in magnitude. The sixth magnitude double star 61 Cygni, has been found to be nearer to us than Sirius, and about three times as far from us as Alpha Centauri. Now, we may assume that each component sends us about one-hundredth part of the light we receive from Alpha Centauri: it follows that the latter star, if removed to the distance at which 61 Cygni lies from us (when its light would of course be diminished to one-ninth of its present value), would outshine either component of that double star more than 11 times. Hence (on the assumption that brightness is a fair measure of real dimensions), each component has a diameter less than one-third that of Alpha Centauri. We may roughly estimate the volume of each at about $\frac{1}{30}$th of that of the latter star. So that, remembering what has already been shown respecting the relation between Alpha Centauri and our sun, the two suns which form the double star 61 Cygni would each have a diameter equal to about $\frac{17}{30}$ths of the sun's, and a volume equal to about $\frac{2}{11}$ths of his. The sum of their volumes would be therefore about one-third of his; and it will presently appear

that a perfectly distinct method of estimation tends to show that the sum of their masses bears about the same proportion to the sun's mass.

But here at once we have evidence that there is a very wide range of magnitude among the fixed stars. We have seen reason to believe that Sirius is 2,688 times as large as the sun, while each of the suns forming the double star 61 Cygni would appear to have a volume less than one-fifth of our sun's, and therefore less than $\frac{1}{13,500}$ths of the volume of Sirius. So that, by considering only three cases, we have found tolerably clear evidence of a range of variety in volume, reminding us forcibly of that which we recognise in the solar system. We cannot suppose that these three cases, which have been selected at random—so far as the question of volume is concerned—indicate anything like the real limits within which the fixed stars differ in magnitude. So that we may confidently accept, as the most probable conclusion from the evidence before us, that the range of real magnitude among the fixed stars is very far greater than Sir W. Herschel was led to anticipate when, nearly a century ago, he began his researches into the sidereal system.

But it is not sufficient that we should thus form an estimate of the nature of the fixed stars from the amount of light they send to us. It is desirable—and fortunately it is practicable—to obtain information as to the absolute mass or weight of some of the fixed stars, and further, to ascertain of what substances they may be composed, and in what condition those sub-

stances may exist. Mere lights, however glorious, or however wide the sphere within which they displayed their splendours, would not be fit to sway the motions of orbs resembling those which circle around our sun. Nor would such lights serve to indicate to the astronomer that, out yonder, myriads of millions of miles beyond the extreme limits of the solar system, there exist materials suited to form the substance of worlds resembling our own.

It seems a strange circumstance that astronomers should be able to form a more exact and trustworthy estimate of the weight of certain fixed stars than they can hope to form respecting the volume of any of those bodies.

Let us consider the evidence.

I have spoken of the star 61 Cygni as a double star. The smaller star shows very clear indications of orbital motion around its primary. That the two are associated together, and not merely seen (as it were by accident), nearly in the same line of view, is indeed certain, because that peculiarly large proper motion already referred to is shared in by both. But many stars may be physically associated, and yet the distance really separating them may enormously exceed that by which they seem to be separated—since the line joining them is not necessarily square to the line of sight. The components of the star 61 Cygni have been carefully watched, however, and their motions show that they are circling round each other in a plane nearly square to the line of sight. The distance

separating them is probably about half as large again as the distance of Neptune from the sun.

The period of revolution appears to be about 520 years, which is more than three times as great as the period of Neptune. Now we know that a planet, placed at a distance from the sun equal to that which separates the components of 61 Cygni, would occupy a much less period than 520 years in completing a revolution; in fact, its period would be about 300 years. Hence it follows that the components of 61 Cygni are attracted together less forcibly than Neptune is attracted towards the sun, and therefore that the sum of their masses must be less than the sun's mass. It is easy to compute the actual proportion, and we find, on doing this, that the two components of 61 Cygni, taken together, weigh about one-third as much as our sun.[1]

The star Alpha Centauri is also a binary system, and though it has not been so systematically observed as 61 Cygni, some astronomers believe that its period has been even more satisfactorily determined. Indeed there are peculiarities in the motion of 61 Cygni which, without throwing doubt on the general conclusions deduced above, yet suggest that a third (probably opaque) orb affects the motions of the other two. From a careful comparison of all the observations made in

[1] It may be easily shown that if a pair of bodies circling around each other at a certain distance take a certain time T in effecting a revolution, while another pair at the same distance take a time t, the former pair, taken together, have a weight which bears to the weight of the latter pair the ratio of t^2 to T^2.

recent times on Alpha Centauri, Mr. Hind has assigned to the components a period of revolution of about eighty-one years, and a mean distance of 13·6 seconds of arc, corresponding to a real distance exceeding the earth's distance from the sun some fifteen times. Since a planet placed at this distance from the sun would occupy less than sixty years in completing a revolution round that body, it follows that the mass of the two components of Alpha Centauri must be less than that of the sun. This result (if the data be considered trustworthy) would indicate a considerable difference between the condition of the star and that of our sun; for we have seen that the star gives out much more light than the sun. However, I believe that many years must elapse before we can regard the period of Alpha Centauri as satisfactorily determined.[1]

Still, we have conclusive evidence in this case, as in that of the star 61 Cygni, that the component stars

[1] Mr. Powell supplies the most satisfactory elements of the orbit yet given, since he founds his estimate on a more complete series of observations. He assigns to the system a period of $76\frac{1}{4}$ years, and a mean distance of 20·13 seconds of arc, corresponding to a real distance about 22 times as great as the earth's distance from the sun. A planet at this distance from the sun would occupy about 103 years in completing a revolution. Hence the mass of the two components of Alpha Centauri turns out to be greater than that of the sun—instead of less, as when Mr. Hind's elements were used. This corresponds with the measurement of the star's light, though the disproportion of the masses calculated in this way is not so considerable as it would be if the masses were inferred from the light of Alpha Centauri. By applying the fomrula of the preceding note, it will easily be found that with Mr. Powell's elements the mass of Alpha Centauri (both components) equals about twice that of our sun.

are really bodies of enormous weight, and consequently well fitted to sway the motions of families of planets. We conclude, therefore, that the fixed stars generally are *suns*, not mere *lights*; and further, we are led to believe that there must be a general similarity in the conditions under which these bodies and our own sun emit light. And thus we are led to recognise other stars also—though yet unweighed—as massive orbs, not merely supplying light to other worlds travelling around them, but regulating by their attractive influences the orbital motions of their dependent worlds.

But we owe to the revelations of the spectroscope the complete proof of these matters, besides evidence on other and equally interesting points.

It had long been known that the spectra of the fixed stars present a general resemblance to the solar spectrum, though of course very much fainter; and that dark lines can be seen in these spectra, some of which correspond with those in the sun's spectrum while others seem to be new. So soon as the great discovery effected by Kirchhoff had been announced, it was seen at once that these dark lines in the stellar spectra afford the means of determining the constitution of the stars. It was only necessary that these lines should be identified by their correspondence with the lines belonging to known elements, in order to prove that these elements exist in the substance of the star. But although the principle on which researches were to be conducted was sufficiently simple, many difficulties had to be encountered. Indeed, the attempts

made by Airy, Secchi, and Rutherfurd to solve the problem of determining the constitution of the stars by means of spectroscopic analysis were unsuccessful; and it was not until Mr. Huggins and Professor Miller commenced their famous series of researches that the problem can be said to have been fairly mastered.

Even in the hands of these eminent physicists the work was difficult and its progress tedious. The weather necessary for the successful prosecution of so delicate a method of inquiry does not often prevail in our variable climate. The comparison between the dark lines in the stellar spectra and the bright lines belonging to various elements was not only a delicate and laborious task, but was singularly painful to the eyes. And other difficulties into which I have not space to enter here had to be encountered and overcome.

But undeterred by these difficulties, the two physicists persevered in their researches, and were rewarded by results so interesting and important that their discovery may be said to constitute the most remarkable era in the history of sidereal research since the completion of the star-gaugings of the elder Herschel.

Two bright stars, Betelgeux, the leading brilliant of Orion, and Aldebaran, the chief star of Taurus, were examined with special care. Mr. Huggins remarks that the spectra of these stars are as rich in lines as the solar spectrum itself. The places of no less than eighty lines in the spectrum of Betelgeux were accurately measured, while as many as seventy lines had their

places assigned to them in the spectrum of Aldebaran.

With respect to the former spectrum, Mr. Huggins remarks that it is most complex and remarkable. 'Strong groups of lines are visible, especially in the red, the green, and the blue portions'; a peculiarity, it may be remarked in passing, which serves to account for the well-marked orange colour of this star.

Now here already we have very decided evidence as to the nature of the star; since the very fact that its spectrum presents the same general appearance as the solar spectrum proves conclusively that the star is an incandescent body, whose light comes to us through certain vapours corresponding to those which surround the sun. Nor should we be able to regard the star as other than a sun, even though none of the elements known to us should appear to be present in its substance or in the vapours surrounding it. For clearly we have no reason for believing that worlds can be formed out of those elements only with which we are acquainted, unless we find as we proceed that those elements actually do compose the suns which form the sidereal system. Of course, if this shall appear to be the case, our conclusions respecting the nature of the stars will be very much strengthened.

Now, when Professor Miller and Mr. Huggins compared the lines in the spectrum of Betelgeux with the bright lines of certain terrestrial elements, they found that some of these elements do actually exist in the vaporous envelope of the stars. Thus sodium,

magnesium, calcium, iron, and bismuth are present in Betelgeux. The lines of hydrogen, which are so well marked in the solar spectrum, are not seen in the spectrum of Betelgeux. We are not to conclude from this that hydrogen does not exist in the composition of the star. We know that certain parts of the solar disc, when examined with the spectroscope, do not at all times exhibit the hydrogen lines, or may even present them as bright instead of dark lines. It may well be that in Betelgeux hydrogen exists under such conditions that the amount of light it sends forth is nearly equivalent to the amount it absorbs, in which case its characteristic lines would not be easily discernible. In fact, it is important to notice generally that while there can be no mistaking the positive evidence afforded by the spectroscope as to the existence of any element in sun or star, the negative evidence supplied by the absence of particular lines is not to be regarded as decisive.

In the case of Aldebaran the two physicists were able to establish the existence of sodium, magnesium, hydrogen, calcium, iron, bismuth, tellurium, antimony, and mercury in the vapours surrounding the star.

Besides these stars fifty others were examined. The brilliant Sirius exhibits a spectrum of great beauty, though the low altitude which this star attains in our latitudes renders the observation of the finer lines exceedingly difficult. But the two physicists were able to show that sodium, magnesium, hydrogen, and probably iron, exist in this gigantic sun.

All the stars examined exhibit spectra crossed by numerous lines, and in a great number of the spectra lines belonging to known terrestrial elements were detected.

And now let us consider the general bearing of these interesting discoveries.

In the first place, we are forced to recognise in the stars *real suns*, not mere lights. Doubtless Whewell did well in pointing out that astronomers had no right to regard the stars as suns until they had some evidence that these orbs resemble the sun in other respects than in size, mass, or luminosity. And as in his day it appeared altogether unlikely that such evidence should be obtained, a real limit seemed placed to the speculations which men might form as to the existence of other planetary systems besides those circling around the sun.

But now we have precisely that evidence which Whewell required. We see that the stars are constituted in the same general way as the sun, and that further they even contain elements identical with those which exist in his substance. There is not indeed in every case, perhaps there may not be in any case, an exact identity of composition between the stars and our sun, or between star and star. But this was no more to have been looked for than an exact identity of physical habitudes amongst the members of the solar system. That general resemblance of structure which indicates a general resemblance in the purposes which the celestial bodies are intended to subserve, is undoubtedly

evident when we compare the stars either with our sun or with each other.

I have already spoken of the conclusions to be drawn from the existence of the same materials in the substance of the sun that exist around us on this earth. I have shown that we are compelled to regard this general resemblance of structure as sufficient to prove that the other planets resemble the earth, since we have no reason to believe that our earth bears an exceptionally close resemblance to the sun as respects the elements of which she is composed.

Since, then, we have reason to believe that all the planets which circle around the sun are constituted of the same materials which exist in his substance, though these materials are not necessarily nor probably combined in the same proportions throughout the solar system, we have every reason which analogy can give us for believing that the planets circling around Betelgeux or Aldebaran are constituted of the same materials which exist in the substance of their central luminary.

Thus we are led to a number of interesting conclusions even respecting orbs which no telescope that man can construct is likely to reveal to his scrutiny. The existence of such elements as sodium or calcium in those other worlds suggests the probable existence of the familiar compounds of these metals—soda, salt, lime, and the rest. Again, the existence of iron and other metals of the same class carries our minds to the various useful purposes which these metals are made to subserve on the earth. We are at once invited to

recognise that the orbs circling around those distant suns are not merely the abode of life, but that intelligent creatures, capable of applying these metals to useful purposes, may exist in those worlds. We need not conclude, indeed, that at the present moment every one of those worlds is peopled with intelligent beings, because we have good reason for believing that throughout an enormous proportion of the time during which our earth has existed as a world no intelligent use has been made of the supplies of metal existing in her substance. But that at some time or other those worlds have been or will be the abode of intelligent creatures seems to be a conclusion very fairly deducible from what we now know of their probable structure.

But secondly, apart from the information afforded by the spectroscope respecting the materials of which the stars are composed, the nature of the stellar spectra serves to prove most conclusively that the stars, besides supplying light to the worlds which circle around them, radiate heat also to them. Even if we were not certain that elements which are only vaporised at a very high temperature exist in the vaporous envelopes of the stars, yet the very nature of the light sent out by the stars indicates that these orbs are incandescent through intensity of heat. When we find that the spectrum of the moon's light resembles the solar spectrum, we do not indeed conclude that the moon is as intensely heated as the sun, because we know that the moon is not self-luminous. But in the case of self-

luminous bodies like the stars, we can conclude from the very nature of their spectra that these orbs are intensely heated. Of course we are rendered absolutely certain of this when we find that iron and other metals exist in the form of vapour in the stellar atmospheres.

The vast supplies of heat thus emitted by the stars not only suggest the conclusion that there must be worlds around these orbs for which those heat-supplies are intended, but point to the existence in those worlds of the various forms of force into which heat may be transmuted. We know that the sun's heat poured upon our earth is stored up in vegetable and animal forms of life; is present in all the phenomena of nature—in winds, and clouds, and rain, in thunder and lightning, storm and hail; and that even the works of man are performed by virtue of the solar heat-supplies. Thus the fact that the stars send forth heat to the worlds which circle around them suggests at once the thought that on those worlds there must exist vegetable and animal forms of life; that natural phenomena, such as we are familiar with as due to the solar heat, must be produced in those worlds by the heat of their central sun; and that works such as those which man undertakes on earth—works in which intelligent creatures use Nature's powers to master Nature to their purposes—may go on in the worlds which circle around Aldebaran and Betelgeux, around Vega, Capella, and the blazing Sirius.

Recently it has even been found possible to render the stellar heat sensible to terrestrial observation—by methods which need not here be inquired into. Nay, the task of measuring the amount of heat received from certain stars has not been thought too difficult. Mr. Stone, making use of the powers of the great equatorial of the Greenwich Observatory, and ingeniously overcoming the numerous difficulties which exist in a research of such exceeding delicacy, has arrived at the conclusion that Arcturus sends us about as much heat as would be received from a three-inch cube full of boiling water, and placed at a distance of 383 yards. Vega, which shines, according to Sir J. Herschel, with about two-thirds the light of Arcturus, gives out about the same proportionate amount of heat.[1] But in other instances the heat-giving power of a star has not been found proportional to the amount of light it emits.

[1] Although these results cannot yet be regarded as numerically exact, it may be interesting to consider the amount of heat given out by Arcturus in relation to the light sent us by this star, the more so as this star seems (from the nature of its spectrum) to resemble the sun very closely in constitution.

The light sent to us by Arcturus is equal to about three-fourths of that supplied by Alpha Centauri, or about $\frac{1}{21,000,000,000}$th part of the light we receive from the sun. Now Mr. Stone estimates the direct heating effect of Arcturus at 0°·00,000,127 Fahrenheit, making due allowance for the effect of the object-glass in concentrating and absorbing the heat. It will be seen at once that, according to this estimate, the heating power of Arcturus bears a very much greater proportion to that of the sun than the respective light-giving powers of the luminaries bear to each other. This seems to throw some doubt on the correctness of the estimate either of the light-giving or of the heat-giving power of the star.

The variation of many fixed stars in lustre at once forms a new bond of association between the stars and the sun—which we have seen to be in reality a variable star—and suggests interesting inquiries as to the existence of variation in the emission of heat. Some of the stellar variations of light are so much more marked than those noticed in the case of our own sun that we can scarcely conceive how creatures resembling any with which we are acquainted could endure the effects of correspondingly important variations of heat; nay, in some instances we seem compelled to withhold our belief in the existence of habitable systems around certain fixed stars. The star Eta Argûs, for example, which sometimes blazes out with a light surpassing that of any of the stars in the northern hemisphere, while at other times it falls to the sixth magnitude, can hardly be regarded as fit to be the centre of a system of worlds. I pass over such variable stars as the one which recently blazed out in the Northern Crown, because in a case of this sort the star may be regarded as really a small orb, and its sudden lustre as due to some exceptional occurrence, leading (as the spectrum of the star seemed to show) to a temporary conflagration. But Eta Argûs, and Mira Ceti seem to belong to a different category altogether, since it is probable as respects the former, and certain as respects the latter, that their appearance as stars of the leading magnitudes is not accidental, but part of a systematic series of changes.

It remains only to be mentioned that, besides light and heat, the stars emit actinic rays. This is proved decisively by the fact that the stars can be made to photograph themselves. It has been found, however, that the actinic power of a star, like its heat-giving power, is not by any means proportional to the star's light. So that in this respect, as in the material constitution of the stars, we find specific varieties even amid those very features which indicate most strikingly the general resemblance which exists between the suns constituting the sidereal system.

To sum up what we have learned so far from the study of the starry heavens—we see that, besides our sun, there are myriads of other suns in the immensity of space; that these suns are large and massive bodies, capable of swaying by their attraction systems of worlds as important as those which circle around the sun; that these suns are formed of elements similar to those which constitute our own sun, so that the worlds which circle round them may be regarded as in all probability similar in constitution to this earth; and that from these suns all the forms of force which we know to be necessary to the existence of organised beings on our earth are abundantly emitted. It seems reasonable to conclude that these suns are girt round by dependent systems of worlds. Though we cannot, as in the case of the solar system, actually see such worlds, yet the mind presents them before us, various in size, various in structure, infinitely various in their physical condition and habitudes.

CHAPTER XI.

OF MINOR STARS, AND OF THE DISTRIBUTION OF STARS IN SPACE.

It has been so long a received opinion that a general uniformity of magnitude and distribution characterises the stellar system that it is with some diffidence I venture to express a different view. And here let me not be misunderstood. I am fully sensible that it is only in certain popular treatises of astronomy that a belief in anything like a real uniformity of structure in the sidereal system is attributed to astronomers of authority. It is not any such imaginary theory that I have now to deal with, however; but with opinions which have found a place in the works of astronomers from whom I very unwillingly differ.

I propose to exhibit the reasons which have led me to believe that, so far from knowing the real figure of the sidereal system, astronomers have not been able to penetrate to its limits in *any* direction; that leading stars, such as those discussed in the preceding chapter, are distributed throughout space to the very farthest limits and beyond the very farthest limits that our most powerful telescopes can attain to; that the stars

are arranged in groups and clustering aggregations, in streams and whorls and spirals, in a manner altogether too complex for us to hope to interpret; and that in these aggregations stars of all degrees of real magnitude are mixed up, from suns as large as Sirius down to orbs which may be smaller than any of the primary planets of the solar system.

Let us consider step by step the evidence we have on these points.

We know, from the existence of double, triple, and multiple stars, in which the components are often very unequal in splendour, that combinations of stars exist in which one or two may be suns like our own, while the rest, or some of the rest, are relatively minute. This, however, has of course long been known; and it is only as a preliminary step in the investigation that I here advance so trite an instance.

Next let us consider such star-clusters as contain orbs of the eighth or ninth magnitude, besides a multitude of minute stars. These clusters must of course be regarded as lying within the sidereal system, since no external galaxies could reasonably be supposed to contain orbs so infinitely transcending even Sirius in magnitude as to shine from beyond the enormous gap separating us from such galaxies with a light exceeding that derived from many stars within the sidereal system. Now, regarding these clusters as forming part and parcel of the sidereal system, we find in the existence of multitudes of minute orbs within their range a proof that diversity of magnitude in schemes

of associated stars is to be regarded as a feature of certain parts, at any rate, of our galaxy ; and we shall therefore be the less surprised if we should find reason for believing that it is a *characteristic peculiarity* of the galactic system.

Now with regard to the nebulæ (resolvable and irresolvable), and their claim to be regarded as external galaxies, I shall have much to say farther on; but I may remark in passing that we have precisely the same reason for believing that many of these objects lie within the range of the solar system, as have been already considered in the case of star-clusters. Their component stars, to be visible at all, *must* fall within the range of distance which astronomers have assigned to the boundaries of the galaxy, since some stars even within this range cease to be separately visible in the most powerful telescopes man has yet constructed. So that when in these objects we see a few or many distinct stars, and a mass of nebulous light which we judge to proceed from an indefinitely large number of minute stars, we again have very decided evidence of the fact that in one and the same region of the sidereal system there may exist leading stars (so to speak) and innumerable stars relatively minute.

With considerations such as these (and I might add many others) to guide us, let us proceed to examine the teachings of the Milky Way itself, that we may see whether that wonderful zone indeed represents, as has been thought, the sidereal system itself, or only an aggregation of minute orbs altogether insignificant

separately, in comparison with our sun or Sirius, Aldebaran or Betelgeux, Vega or Arcturus.

The star-gauging of Sir W. Herschel, interpreted according to his hypothesis of stellar distribution, pointed to an extension of the Milky Way laterally to a distance exceeding some eighty times that which separates us from the first-magnitude stars. So that, regarding sixth-magnitude stars as on the average about ten times as far from us as those of the first magnitude (the usual estimate), we see that the outermost parts of the galaxy must lie (according to Sir W. Herschel's theory) about eight times as far from us as the sphere of the sixth-magnitude stars. Now Sir John Herschel was led by his observations of the southern heavens to so far modify his father's theory as to describe the Milky Way as probably shaped like a flat ring, the stars down to the tenth magnitude being in a sense dissociated from the ring, while he regarded the probable distance of the outermost limits of the ring as 750 times instead of but 80 times the mean distance of the first-magnitude stars. This difference of opinion, it may be remarked, though obviously not surprising when we consider the enormous difficulty of the problem presented by the sidereal system, is yet sufficient to indicate the probability that an important error has been made in the hypothesis which underlies the accepted theories respecting the galaxy. But, be this as it may, in regarding the Milky Way as shaped like a flat ring (cloven through one-half of its circumference) whose medial section

resembles generally the space between the dark concentric circles in the accompanying figure (in which

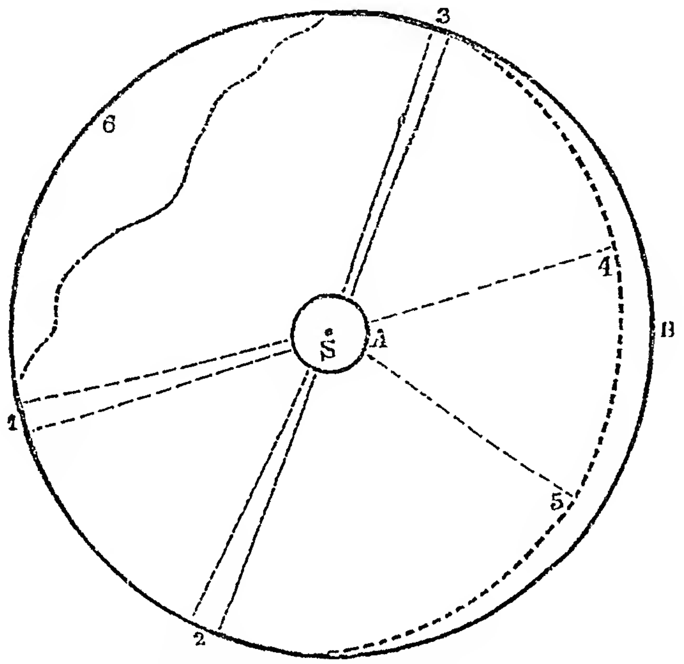


Fig. 2.—The Galactic Cloven Flat Ring (plan).

SB equals eight times SA), I have not adopted a structure which *exaggerates* the difficulties presented

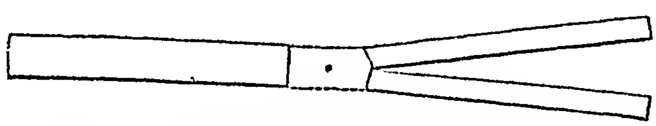


Fig. 3.—The Galactic Cloven Flat Ring (section).

by the disc or ring theory of the Milky Way. The cross-section would be somewhat as shown in fig. 3.

Now, accepting this modified figure, as better according with the results of star-gauging than Sir W.

Herschel's theory that the Milky Way forms a cloven disc, let us consider whether any peculiarities of the Milky Way seem to oppose themselves to this interpretation of its structure.

In the first place, then, there is a gap or rift extending right across the single part of the Milky Way in the constellation Argo; so that we must conceive that from S towards 1, in fig. 2, the flat ring is broken through by some such rift as is indicated by the broken lines in that direction. Next there is, in the constellation Crux, a pear-shaped vacuity of considerable size, and bounded by well defined edges; so that we must conceive that from S towards 2 (fig. 2) the flat ring is tunnelled through by some such passage as is indicated by the dotted lines in that direction. A similar tunnelling, but of different cross-section, must exist in direction S 3 (as shown by the dotted lines) to account for the dark gap in the constellation Cygnus. Next, where the Milky Way is double, a large portion of one branch is discontinuous, so that the upper part of the double portion of the ring in fig. 2 must be supposed removed between the broken lines from S to 4 and 5. Over the so-called double stream there are in places strange convolutions, in others numerous branching and interlacing streams, whose complexity indeed defies description; so that the portion 3 B 2 of the ring must be supposed corrugated in the strangest way, and further to throw out plane and curved sheets of stars presented tangentially towards S. Lastly, the single portion of the Milky Way is very faint indeed

towards 6, so that here we must conceive its figure trenched in upon in the way indicated by the dot-and-peck line.

Thus, even without considering a multitude of minuter peculiarities of structure, we are led to the conclusion that the Milky Way, judged according to the fundamental hypothesis of Sir W. Herschel, has some such shape as I have endeavoured to exhibit in the accompanying figure. Although I have not indicated

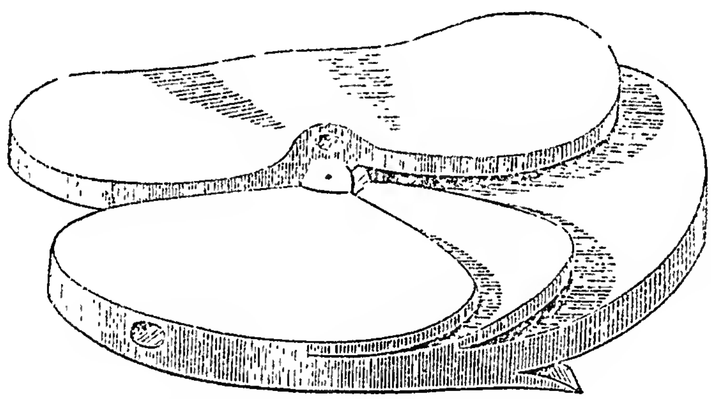


Fig. 4.—The Galactic Flat Ring modified in accordance with the observed peculiarities of the Milky Way.

here the corrugations of the ring, nor a tithe of the various overlapping layers which would be required to account for the appearance of the Milky Way between Centaurus and Ophiuchus, yet the deduced figure is by no means inviting in its simplicity. It is, however, absolutely certain that the sidereal system, as far as its more densely aggregated star-regions are concerned, has some such figure as this, if we are to accept the principle of Sir W. Herschel's star-gaugings.

Now, in turning our thoughts to the recognition of a more simple explanation of observed appearances, it will be well that we should consider some peculiarities of the Milky Way which we have not yet attended to. In the first place, I would invite attention to a peculiarity observed by Sir John Herschel in different parts of the galaxy—the fact, namely, that in places the edge of the Milky Way is quite sharply defined. One half of a telescopic field of view may be quite clear of stars, or show only a few straggling orbs, while the other half presents what has been called a 'Milky Way field'—that is, a region profusely sprinkled with stars, the boundary between the two portions being well defined. When we see that a cluster of objects presents a well-defined edge, what conclusion do we draw as to the position of the object? Is it not in such a case absolutely certain that the distance of the cluster enormously exceeds the distance between its component parts—or in other words, that the observer is far outside the cluster? Many instances will at once suggest themselves to the reader in illustration of this remark.

We conclude, then, that these portions of the Milky Way, at any rate, whether they be regarded as projections or nodules, are definite clustering aggregations very far removed from us. Other parts of the Milky Way *may* also be removed bodily, so to speak, to enormous distances, because a cluster which has not a definite edge may be as far removed as one which has; but certainly *those* portions are.

Next let us consider what opinion we may found on the existence of dark regions in the Milky Way; and here I refer not merely to such large and obvious vacuities as the Coal-sack in Crux or the oval opening in Cygnus, but also to small openings, in which, though they occur even in rich regions of the Milky Way, there is not, according to Sir W. Herschel's description, even a telescopic star to be seen.

Judged apart from preconceived opinions, such openings as these, according to all laws of probability, indicate that the portion of the Milky Way in which they occur has not a very great lateral extension. To return for a moment to fig. 2, it will be seen at once that an aperture extending laterally through a star system so shaped must have a particular direction and be perfectly straight in order to be visible to observers placed, as we are supposed to be, in the central opening. It is altogether improbable that one such opening should exist by accident, and absolutely impossible that many should.[1] We are forced, therefore, to infer that, instead of the enormous lateral extension assigned to the Milky Way, the galaxy has in these places certainly, and elsewhere probably, a lateral extension not greatly exceeding its depth.

It is further to be noted that the lucid stars over

[1] Sir John Herschel distinctly indicated this inference, as he did many other matters which make strongly against the received theory of the sidereal system. Nor was he unconscious of their bearing. Apparently unwilling to press them to their full extent, he was commonly satisfied by noting that they do not seem to accord with views he had elsewhere dwelt upon.

the zone of the heavens which is occupied by the galaxy show a very decided preference for the parts of that zone which are actually traversed by the Milky Way. For instance, we find no stars above the fifth magnitude, and very few of these in the Coal-sacks, or in the rift which crosses the Milky Way in Argo; or, again, in the space which lies between the two branches where the Milky Way is double. If this is an accident it is a very extraordinary one, especially when it is remembered that the region where it occurs is the very part of the heavens where stars of all magnitudes may be expected to be most profusely distributed; that the spaces thus left vacant form no inconsiderable aliquot part of that zone; and that, according to the accepted theory, there is no reason for expecting any peculiarity of the sort.

Thus, again, setting aside preconceived opinions, and judging only according to the evidence, we seem led to regard the coincidence as not accidental, but as indicating that there really is a very close association between the bright stars and those small stars forming the milky light, which, according to the accepted theory, lie so many times farther from us.

But this opinion is absolutely forced upon us when we apply a rigid process of examination to the evidence we have respecting the distribution of the lucid stars over the galactic zone. So far as I am aware, this has not hitherto been attempted. Indeed, independently of the fact that I have not met with any reference to

such an inquiry, although I have had occasion to study very carefully all the works bearing on the subject, I feel confident that the examination I refer to has never yet been attempted, because I am sure that if it had, the result must have been the adoption of views altogether different from those at present accepted. I shall have occasion, farther on, to exhibit the method by which the following results have been obtained, and therefore I content myself in this place with simply stating them:—

The Milky Way covers $\frac{21}{220}$ths of the whole heavens, while the gaps and lacunæ in the Milky Way cover about 1–62nd part. In the Milky Way there are 1,115 lucid stars; in the gaps and lacunæ only 20. So that if the whole heavens were as richly covered with lucid stars as the Milky Way, there would be 11,681 stars visible to the naked eye, instead of the 5,850 actually seen. But if the whole heavens were no more richly strewn with stars than the gaps and lacunæ in the Milky Way, there would be but 1,240 lucid stars. *The Milky Way is, in fine, no less than nine times as richly strewn with lucid stars as its gaps and lacunæ, whereas according to the accepted views no such peculiarities are to be looked for in the distribution of lucid stars over the galactic zone.*

We have here a statistical fact which *must* be accounted for in forming a theory of the sidereal system. I have, indeed, no hesitation in saying that it is the most remarkable feature of the stellar heavens. No one who appreciates the laws of probability will

ascribe it to mere chance distribution.[1] Where, then, is the cause, unless we accept the obvious and simple explanation that the Milky Way *seems* to be thus associated with lucid stars because it *is* associated with them—that in place of being, as has so long been supposed, a congeries of suns many times more distant than the lucid stars, it is formed of myriads of relatively minute orbs compared with which those lucid stars are as the giant planets of our solar system compared with the asteroids?

It is very clear, then, what views we are to form respecting the Milky Way. If the galaxy is, *first*, a clustering aggregation separated from us by an interval comparatively clear of small stars; *secondly*, so shaped that the cross-section of the stream is everywhere not far from a roughly circular figure; and *thirdly*, associated very closely with the bright stars seen in the same field of view, then must its structure be somewhat as shown in fig. 5, in which the discs represent lucid stars (very much exaggerated of course in size), while the fine dotting represents the spiral of relatively minute stars, clustering along the spiral group of leading stars. It will be seen at once how, to an observer placed at S, the various features of the Milky Way can be accounted for by this figure. Towards *a* would lie the gap in

[1] If the clouds of a summer sky arrayed themselves in rank and file so as exactly to correspond to the panes of the window through which I view them as I write, I should not regard the coincidence as more amazing than that involved by the observed relations of the stars if those relations are due to chance distribution.

Argo; towards *b* two branches, one faint, and in part evanescent through vastness of distance, the other forming the brightest part of the spiral; towards *d* the projection in Cepheus; towards *e* the faint part of the Milky Way in Gemini and Monoceros. The Coal-sacks would be simply accounted for by conceiving that branches seen towards the same general direction, but at different distances, do not lie in the same general plane, and so may appear to interlace

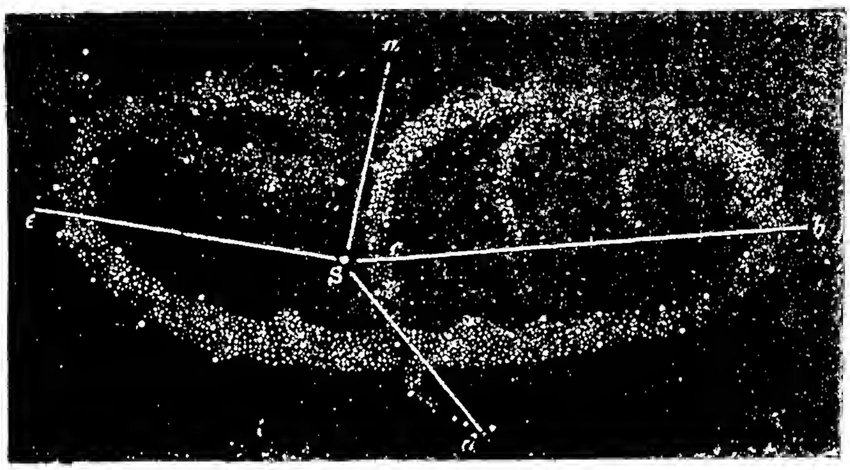


Fig. 5.—The Milky Way regarded as a Spiral.

upon the heavens. We are not only justified in supposing this, but forced to do so by the way in which the stream of milky light is observed to *meander* on its course athwart the heavens. The branching extensions serve very well to account for the appearance of the Milky Way between Centaurus and Ophiuchus, where the interlacing branches and the strange convolutions and clustering aggregations described by Sir John Herschel are chiefly gathered.

I would not have it understood, however, that I at

all insist on the general shape of the spiral shown in fig. 5. On the contrary, that curve is only one out of several which might fairly account for the observed appearance of the Milky Way; and I have often felt inclined to doubt whether a single spiral of this sort is in reality the best way of accounting for the observed appearance of the galactic zone. What I do insist upon as most obviously forced upon us by the evidence is that (1) the apparent streams formed by the Milky Way upon the heavens indicate the existence of real streams in space; and (2) that the lucid stars seen on the stream are really associated with the telescopic stars which form, so to speak, the body of the stream. Whether that stream form a single spiral or several, or *whether, instead of spirals, there may not be a number of streams of small stars, placed at different distances from us, and lying in all directions round the medial plane of the galaxy, but more or less tilted to that plane (the sun not lying within any one of the streams)*, are questions which can only be resolved by the systematic scrutiny of this wonderful zone.

The chief points to be noticed among the considerations flowing from these general views are these:—

In the first place, the only marked difference between the stars of the leading magnitudes (say the first ten) lying in the galactic zone, and those lying without it, consists in the fact that the former are associated with countless multitudes of smaller stars, while the latter appear not to have such attendants, or

not so many of them. We shall see presently that the extra-galactic stars *are* associated, and in a very intimate manner, with groups of very minute stars—of stars so minute indeed as not to be separately discernible—so that astronomers have been led to regard such groups as external galaxies. But except in one region, we do not find outside the galactic zone any appearances reminding us of the aspect of the Milky Way itself. In that region lie the two Magellanic Clouds, resembling the Milky Way in their general appearance, but seen, when placed under telescopic scrutiny, to differ from it in this, that among the minute stars which cause the milky light are numbers of nebulæ, of classes not found commonly, if at all, in the galactic zone.

In the second place, we must conclude that uncounted millions of stars exist which are very minute indeed in comparison with those which we have been led to regard as suns. That these relatively minute orbs may be absolutely large—far larger, for instance, than our own earth—may indeed be accepted as certain. But it is difficult to believe that they subserve purposes similar to those of our own sun. One cannot but see that orbs such as these would not have that permanence of character, as sources of heat-supply, which would seem to be necessary in the case of a real sun. We know, indeed, that among the small stars of the Milky Way there is a proneness to irregular variation which is not recognised, or is altogether exceptional, among the lucid stars. In the neighbour-

hood of the Milky Way, with scarcely an exception, those temporary stars have blazed out which have formed a subject of such perplexity to the thoughtful astronomer. Under what conditions the small orbs in the Milky Way actually exist, whether clusters of them will eventually segregate from their neighbours to form suns, or whether, after long voyaging in spiral and contorted paths under the varying influences of the attractions of leading stars, these minute orbs will, for the most part, be forced to settle down as attendants round the major ones, it is as yet altogether impossible to judge. It may be that they bear the same sort of relation to the leading stars that certain cometic and meteoric families, referred to in Chapter IX., bear to the major planets of the solar system, not being in any case absolutely dependent on any large star, but yet returning in cycles, which must be measured by millions of æons, to temporary dependence on one sun after another; until in the course of time, under the action of processes somewhat resembling those I have conceived to take place in the formation of the solar system, the conditions under which they move will have become so far altered as to lead to the breaking up of the Milky Way into distinct systems. Indeed, as Sir William Herschel was led by other considerations long since to point out, there are signs in parts of the Milky Way which would seem to indicate that several such systems have already reached an advanced stage of development.

But perhaps the most important conclusion de-

ducible from the circumstances I have dwelt upon (assuming my interpretation of them to be in the main correct) is this, that we can no longer suppose we have in any direction pierced to the limits of the sidereal system. So long as a general approach to uniformity of distribution was understood to prevail within that system, there was a ready means of determining when the telescopist had reached in any given direction the limits of the system. To use the words of Professor Nichol, 'When an eye is directed towards a prolonged bed of stars, there is no reason to fancy that it has reached the termination of that stratum so long as there appears behind the luminaries which are individually seen any milky or nebulous light; such light probably arising always from the blended rays of remoter masses. But if, after struggling long with a nebulous ground, we obtain a telescope that gives us additional light with *a perfectly black sky*, we then have every reason the circumstances can furnish on behalf of the supposition that at length we have pierced through the stratum; a probability, indeed, which can be converted into certainty in only one way—viz. when no increase of orbs follows on the application of a still larger instrument.' Sir John Herschel has expressed a similar view, and there can, indeed, be no doubt that, adopting the fundamental hypothesis on which accepted views are founded, the test above described is an absolutely certain one.

But if, instead of penetrating farther and farther into space when 'struggling long with a nebulous

ground' (to use Professor Nichol's striking but somewhat incorrect expression), we have in reality only been searching with more and more minuteness into a definite cluster or stream of stars, we can no longer come to the conclusion he has insisted upon. We have reached the limits of minuteness which the stars of the cluster or stream attain to; we have learned perhaps all that we can learn about that cluster or stream; but we can no more be said to have reached the limits of the sidereal system in that direction than we can be said to have reached the outermost bounds of the universe in the direction of the cluster in Hercules, when that magnificent object has been thoroughly resolved with the telescope.

Here, then, if I have seemed to narrow the limits of the sidereal system by bringing the star-myriads of the Milky Way, which had been regarded as many times farther from us than the lucid stars, into direct association with these luminaries, I make amends by pointing out that in all probability the limits of the sidereal system lie far beyond the range of the most powerful telescopes man has yet constructed. In fact, there is here a somewhat singular interchange of position between the new and the accepted theories. According to the views usually accepted, the small stars in the Milky Way are really as large, on the average, as the lucid stars; whereas, according to my views, they are relatively minute. But accordirg to the accepted theories, the scattered stars of very low magnitude in the extra-galactic heavens must be regarded as rela-

tively minute, since it has been rendered certain, according to those theories, that the limits of the sidereal system are relatively close in this direction, and we cannot suppose these stars to lie beyond those limits (as they must do, if really large). Now, according to my views, there is nothing to prevent these minute stars from including among their number orbs as vast as Sirius, or many times vaster. Nay, even within the galactic zone itself there are stars to which my theory gives as noble proportions as the accepted views. For in the southern Coal-sack there are minute telescopic stars, as Sir John Herschel tells us, and these orbs, according to the accepted views, must be regarded as belonging to the galactic circle, though inexplicably segregated from their fellows. According to the views I have been led to form, many of these telescopic stars must be regarded as suns lying far beyond the galactic spiral, or perhaps associated with outer whorls of this spiral which no telescope made by man can ever reveal to us.

And this leads me to consider two phenomena which are altogether inexplicable, I conceive, on any theory except mine.

The first is the existence of excessively faint streams of light—star-streams, doubtless, though the components are not separately visible—in certain regions of the heavens. Sir John Herschel, who detected this strange phenomenon, speaks of the streams as so very faint that the idea of illusion has continually arisen subsequently; yet he dwells far too clearly on the charac-

teristics of the phenomenon for any doubt to remain as to its reality. The faintest possible stippling of the field of view—the minute points of light being obviously *there*, though it was impossible to see them individually —a mottling which moved with the stars as he moved the tube to and fro, such are the terms in which Sir John Herschel speaks of this interesting phenomenon.

Now no doubt whatever can exist that if these faint streams really belong to the sidereal system they are left altogether unaccounted for by the ordinary views respecting the structure of that system. There is no continuity between the stars composing them and even the minutest telescopic stars visible in the same general direction; so that a vast void must separate them from the outermost of those telescopic stars. According to my theory, they probably belong to outlying whorls of the spiral galaxy, and the telescopic stars seen upon them bear the same relation to them that the lucid stars bear to the Milky Way.

The second point is perhaps even more striking. In certain directions Sir John Herschel recognised the existence of two or more distinctly marked classes of stars, as though, he said, definite sets of stars, separated by comparatively void intervals, lay in those directions. It is clear that this association of the stars into sets is as distinctly opposed to the views ordinarily accepted as it is obviously an arrangement to be expected according to my theory of the constitution of the sidereal system.

But we need not proceed beyond the sphere of the

lucid stars in order to find evidence of such association. Amazing and incredible as it may at first sight appear, those orbs which have been visible during so many thousands of years before the telescope was invented, the stars which Hevelius and Ptolemy could chart and catalogue, have been teaching men with unmistakable clearness a lesson which hitherto has been persistently neglected.

It had long since occurred to me that the lucid stars are not spread over the heavens with that general approach to uniformity required by the accepted theories. In constructing my gnomonic charts of the heavens, though these include only the stars of the first five orders of magnitude, I recognised clear traces of the existence of star-streams and star-reticulations, rich regions and barren spaces, which the laws of probability would not permit me to regard as due to chance-distribution.[1]

[1] I tried the experiment of distributing 2,000 points at random over a square surface. It is not quite so easy as it might at first be thought to secure a perfectly random distribution. The plan I adopted was the following:—Taking a book full of numerals (I used a table of logarithms), and opening it at random, I brought the point of a pencil down on the open page. Whatever numeral the pencil-point fell nearest to, I entered in a long list of numerals formed on this plan. Then dividing the sides of my square into 100 parts, and the square itself into 10,000 small squares, I took the numerals in sets of four to indicate the places of a number of dots. Thus, supposing the first four numerals to be 2371, I took that small square which was the twenty-third from one side of the large square and the seventy-first from an adjacent side, and marked a dot in that square. Doing this for 2,000 dots I had a perfectly random distribution. No well-marked streams, reticulations, vacuities, or rich regions could be recognised in the result.

But while my larger atlas was in progress this opinion grew into conviction. In some of the maps the bareness of certain regions contrasted so strangely with the richness of others as to give an unfinished appearance to the work. I determined that as soon as I had leisure I would combine in two large maps of hemispheres the twelve maps of my atlas, in order to see what the real relations might be which were only partially indicated in maps covering but a tenth part of the heavens.[1] I selected for this purpose a mode of projection described in my 'Hand-book of the Stars,' but first suggested, I have since found, by Sir John Herschel. It represents equal areas on the celestial sphere by equal areas *in plano*; so that, though there is considerable distortion, the real relative richness of different regions of the stellar heavens is accurately represented. The accompanying large plate represents a reduction of the maps thus constructed.

I leave the exhibition of minor peculiarities of stellar distribution — star-streams, star-reticulations, star-clusters, and so on—to the maps themselves, which will, I think, be found to well repay careful study. But I applied to the original maps a further process of investigation in order to deduce the real characteristics of the rich and barren regions I had noticed while con-

I consider, too, that where so many dots were marked in, one trial was as good as a large number.

[1] The maps of my atlas overlap each of the twelve, including a tenth part of the celestial sphere. The reader may perhaps be surprised that the peculiarities I refer to should not have been noticed while other star atlases were constructed. But the great distortion in all former star atlases will suffice to explain the circumstance.

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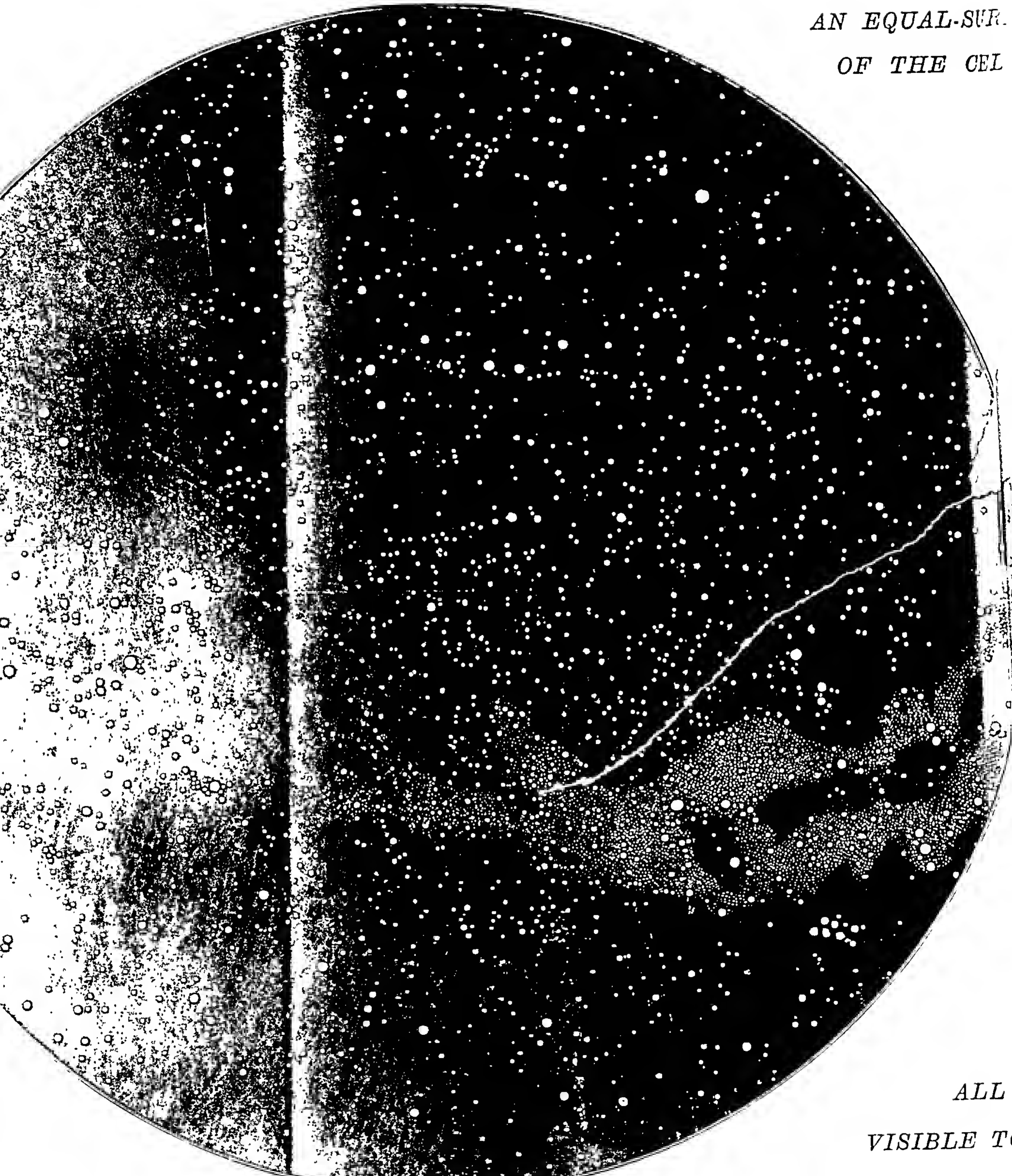

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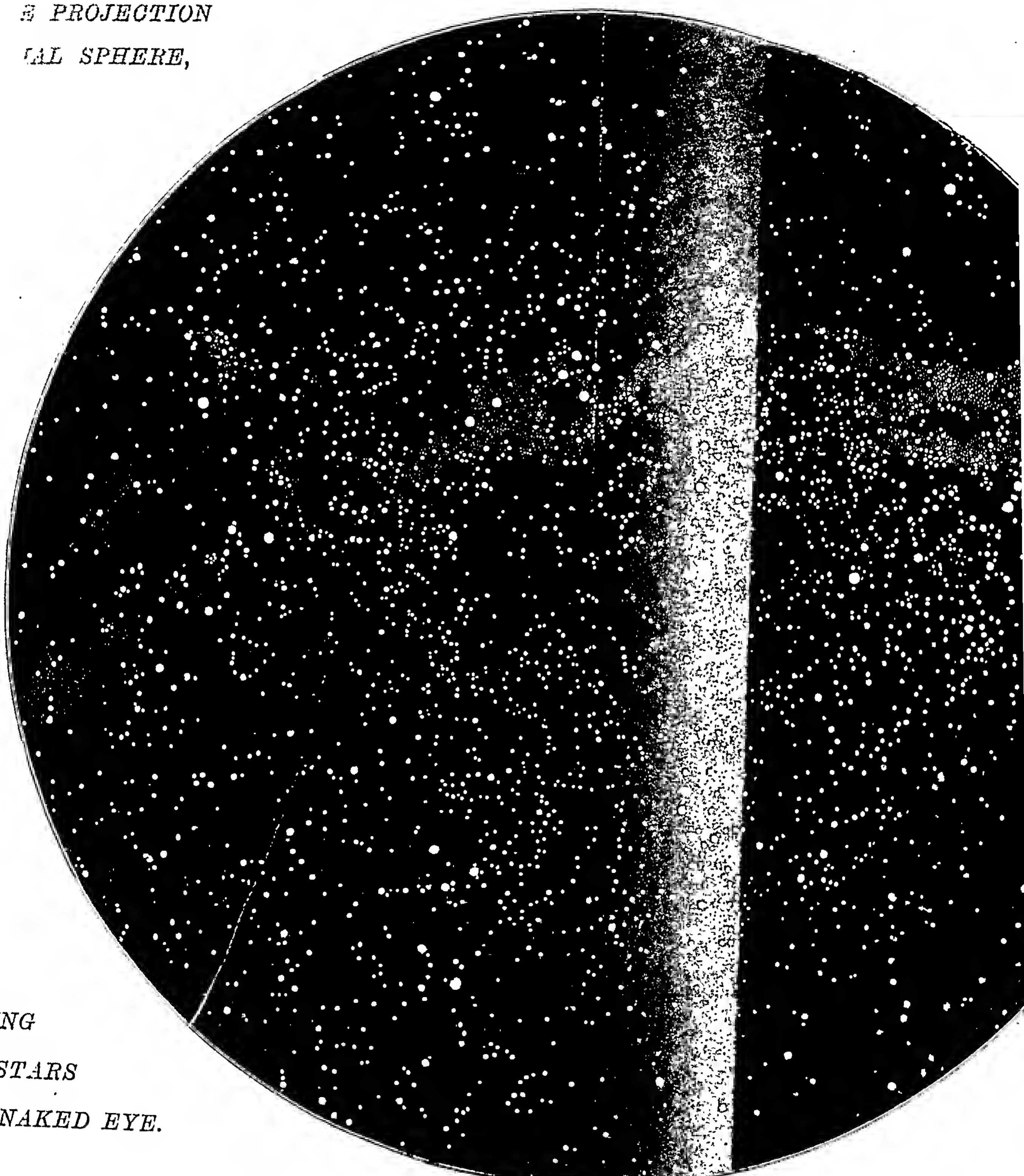
II.—SOUTHERN HEMISPHERE.



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structing the large atlas. The plan I adopted was sufficiently simple. I cut out the portions of the map which seemed richly or sparsely dotted with stars, and weighed the paper. The relative weights of different portions gave me the relative areas, and thus it was only necessary to count the number of stars in order to determine the relative richness of stellar distribution.

The regions I selected for special examination by this method were the following:—

1. A nearly circular region in the northern heavens surrounding the projection of the Milky Way towards the North Pole, and having a radius of about one-fifth of the map's diameter. I call this *the richest northern region.*

2. A much larger region, including the last, and occupying the middle of the northern map. I call this the *rich central northern region.*

3. A large circular region, occupying the middle of the southern map. I call this the *rich central southern region.*

4. A somewhat triangular region, included within the last, and occupying the upper right-hand part of the southern map (between Sirius, Canopus, and the constellation Crux). I call this *the richest southern region.*

5–6. The remaining, or outer, parts of the northern and southern maps.

7–8. Two very barren regions bordering on the rich northern central region—one towards the lower half of the northern map, the other towards the

upper half. I call these *the poorer northern regions I. and* II.

9–10. Two corresponding southern regions, one occupying the upper right-hand quadrant of the northern map, the other occupying the lower quadrant of the same side. These I call *the poorer southern regions* I. *and* II.

Lastly, I take the northern and southern portions of the Milky Way, and the gaps and lacunæ in the Milky Way.

Having selected these regions for comparison,[1] and applied to them separately 'the scissors and balance' test, I have deduced the following results:—

Name of Region	Area (Area of hemisphere, as 1)	Number of lucid stars	Richness (Average = 5,850)
NORTHERN—			
Milky Way	$\frac{1}{11}$	497	9,940
Richest Region . .	$\frac{3}{22}$	622	9,050
Rich Central do. . .	$\frac{5}{11}$	1,420	6,248
Outer do.	$\frac{6}{11}$	1,070	3,923
Poor do. (I.) . . .	$\frac{3}{22}$	201	2,948
Do. do. (II.) . . .	$\frac{3}{22}$	175	2,567
Gaps in Milky Way . .	$\frac{1}{62}$	20	1,240
SOUTHERN—			
Poor Region (I.) . .	$\frac{3}{22}$	161	2,361
Do. do. (II.) .	$\frac{3}{22}$	216	3,198
Outer do.	$\frac{1}{2}$	893	3,572
Rich Central do. .	$\frac{1}{2}$	2,467	9,868
Richest do. . . .	$\frac{3}{22}$	895	13,126
Milky Way . .	$\frac{1}{10}$	618	13,596
Milky Way as a whole .	$\frac{21}{220}$ths of sphere	1,115	11,681

[1] There is some room for choice in taking the boundaries of the regions, and for convenience I have so taken them that the smaller regions are made equal to each other in area.

But surprising as these results may seem, the question whether such peculiarities of stellar arrangement may not be regarded as due to chance-distribution remains to be considered.

It has been so often urged that amongst a very large number of stars such peculiarities might be looked for that many will be disposed to dispute the assertion that *uniformity, not peculiarity* of distribution, is to be expected among a large number of points spread over any surface according to true chance-distribution. Yet so it is. The laws of probability tell us that whereas among a few such points peculiarities need not surprise us, uniformity of distribution will inevitably appear where there are many points, unless some special law is in operation to prevent such a result.[1]

To illustrate the amazing weight of probability in favour of the existence of laws of aggregation and segregation among the lucid stars, I will state the result of a process of calculation I have applied (in accordance with the recognised laws for determining probabilities) to the statistical relations presented by the two rich regions in the northern and southern hemispheres:—

The vast scale of the universe of the nebulæ (or, as

[1] As a familiar illustration of the law of probabilities in question, we may take the case of tossing a coin. If a coin be tossed six times, there will be nothing very surprising in the recurrence of 'head' (say) four, five, or even six times—that is, if two-thirds, five-sixths, or the whole of the series of results are of one kind. But if we calculate the chance that in six thousand tossings there should be so many as four thousand results of one kind, we find it so minute that the concurrent testimony of all mankind could never make it credible that such an event had happened. The probability is the same as that referred to in the text a few lines further on.

it has been called, the *universe of universes*), as conceived by Sir W. Herschel, is well known. *Now, the probability that the observed relation results from chance-distribution is many millions of times less than the chance of drawing one particular grain, smaller many million-fold than the minutest object visible in the most powerful microscope and lying within a space compactly filled with similar grains, and large enough to enclose many millions of the universes of universes.*

The probability that the more remarkable relations presented by the richest and poorest smaller regions result from chance-distribution is indefinitely more minute even than this inconceivably minute probability.

But since the above lines were written I have gone much further with the illustration of this matter by star-charting. For I have combined in a single chart all the forty large folio charts of Argelander's Atlas, containing no less than 324,198 stars, all presented on the same isographic projection as the accompanying chart. In this map of many stars, the place of the Milky Way is actually 'mapped in' by the stars themselves, not as here, by a separate indication. I would refer those who desire fuller information respecting the arrangements of the stars in space to this chart and its explanation (published by Mr. Brothers, of 14 St. Ann Square, Manchester).

The evidence in favour of special laws of stellar distribution is, however, far from exhausted.[1]

[1] Indeed, I am unable, within the space here available to me, even to touch on a tenth part of the evidence I have gathered together in my note-books and portfolio of charts.

Quite early in my consideration of the subject I am now upon, the idea suggested itself to me that in the proper motions of the stars we have a means of forming an estimate of the distances of these orbs; and further, of detecting any laws associating them together, whether into streams or clusters; and that the evidence thus obtained was likely to be in many respects more trustworthy than that afforded by the apparent magnitudes of the stars. Two processes of inquiry suggested themselves. The first consisted in a careful comparison of the mean motions of stars of different apparent size, in order to determine whether, on the average, small stars are so far off that we can look upon them as in reality no smaller on the average than those which appear larger. The second consisted in charting down the proper motions, so as to detect any signs of star-drift which might haply appear in different parts of the heavens. I confess that I had not by any means expected results so strikingly confirmatory of my views as those I actually obtained.

The first method of inquiry, instead of giving an average amount of proper motion to the smaller stars somewhat, or perhaps even considerably, greater than was to be expected, according to the theory which sets these stars at an enormous distance, actually gave them a mean motion *equal* to that of stars of the first three magnitudes. It became evident, then, that not only are small stars (I am here speaking of stars visible to the naked eye) mixed up as I had thought with bright stars visible in the same general direction, but

that distance is less available to explain the smallness of the stars even than I had supposed. I had thought that certainly a large proportion of the small stars must in reality be very far from us; but it appeared that the proportion of stars whose smallness is so to be accounted for is in reality exceedingly minute. There must therefore be myriads of really small stars for every leading orb.

The second method of research led to the strange result that in many parts of the heavens a community of motion can be recognised, among star-groups far larger in extent than any such groups as I had expected to find thus drifting through space. Knowing that whatever view we form of the sidereal universe, we must yet recognise the fact that in every direction stars at very different distances are visible, I had not hoped to find over any large region of space the traces of a community of motion. Nor even in small regions had I hoped to recognise very decided traces of star-drift, because I was conscious that, even with three or four stars really forming a drifting group, there would nearly always be found three or four others, either much farther off or much nearer, and altogether dissociated from the drifting set. Indeed, I imagined, when I began the inquiry, that the most remarkable instance of star-drift in the heavens was that detected (though differently explained) by Mädler in the constellation Taurus.

I found, however, that in other regions a far more obvious tendency to drift can be recognised. Perhaps

the most remarkable instance of all is that illustrated in the accompanying plate. This picture represents the motions in the constellations Cancer and Gemini. It will be noticed that though here and there stars apparently not belonging to the system appear in the same range of view, yet the star-drift is unmistakable. The general parallelism of motion is very striking; and the difference in the amount of motion observed in different stars is only what was to be expected in a star-group whose range in distance, if equivalent to its lateral extent, must be such as fully to account for the range in the amount of apparent motion.

Fig. 6 exhibits one out of many parts of the heavens in which different sets of stars are observed to be drifting in different ways.

It will be seen that here there are three sets—those included in the space *a*, those in space *b*, and those left unenclosed. These groups are very obviously drifting, each in its special direction. The stars within the space *b* are β, γ, δ, ε, and ζ of the Greater Bear with three smaller stars. Their drift is, I think, most significant. If in truth the parallelism and equality of motion are to be regarded as accidental, the coincidence is one of a most remarkable character. But such an interpretation can no longer be looked upon as admissible. For Mr. Huggins has found that these stars β, γ δ, ε, and ζ are all receding from the earth at the rate of about seventeen miles per second. This was the one piece of evidence necessary to establish my theory, that these stars form

a drifting system. But the peculiarity is only one of a series of instances, some of which are scarcely less striking. One of these is presented in fig. 7, in which the proper motions in the stars α, β, and γ Arietis,

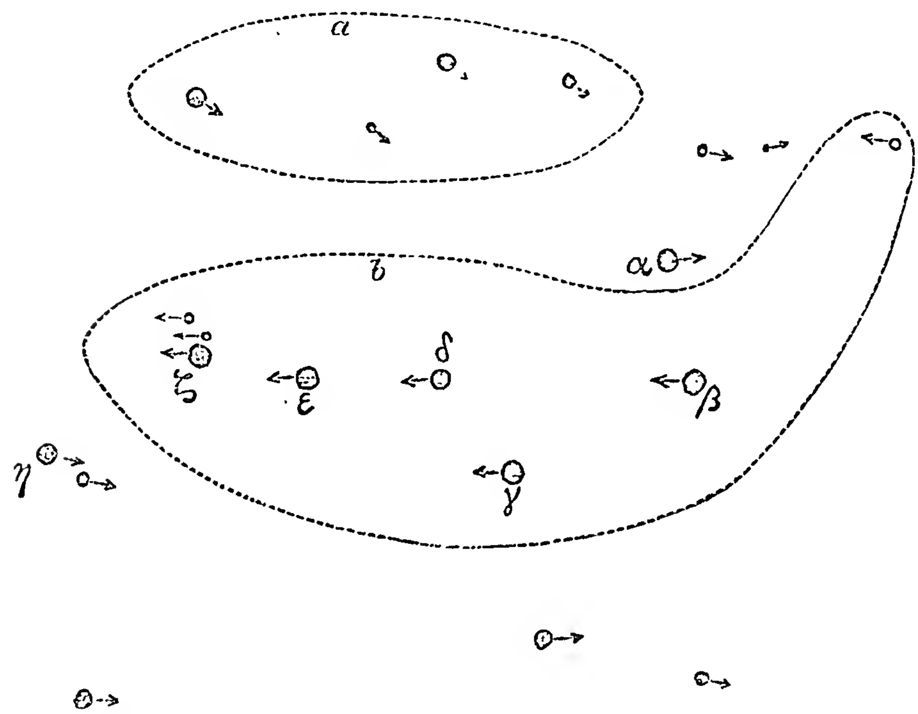

Fig. 6.—Observed Proper Motions of Stars in Ursa Major and Neighbourhood.

and four other stars in the neighbourhood, are exhibited.[1]

Here β and γ may be regarded as drifting with α, but having a motion of their own in addition, sufficing to account for the want of strict parallelism between

[1] In all three figures the proper motion indicated by the length of the arrow attached to a star corresponds to the star's motion in 36,000 years.

their apparent motion and that of α. The other stars seem obviously to belong to the same system.

I am led by the facts which have here been briefly considered rather to urge those who have time and inclination to inquire carefully into the minuter details of the sidereal heavens than to insist on any views of my own. While I recognise the wisdom and necessity of that course which the Herschels adopted in taking a wide view of the sidereal system, and in dealing

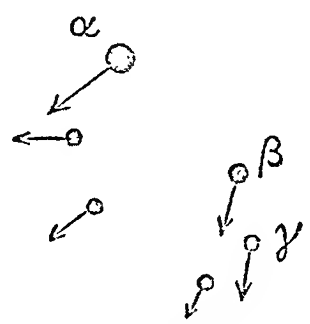

Fig. 7.—Observed Proper Motions of Stars in Head of Aries.

rather with general results than with special peculiarities, I think the time has come when another course is possible and advisable. The Herschels having surveyed the field of heaven, it behoves us now to go over it with a close and searching scrutiny. To consider averages *now* is to level the scarcely perceptible undulations in our field of research, as well as its better marked ridges or depressions; whereas we require, on the contrary, to exaggerate the variations of level, so that we may determine with more certainty what are the peculiarities presented by that most interesting field to man's contemplation. Or,

to change the illustration, and to quote the words of the greatest modern master of that kind of research which I have been advocating—'We must not be deterred from dwelling consecutively and closely on these speculative views by any idea of their hopelessness which the objectors against "paper astronomy" may entertain, or by the real slenderness of the material threads out of which any connected theory of the universe has (at present) to be woven. "*Hypotheses fingo*"[1] in this stage of our knowledge is quite as good a motto as Newton's "*Non fingo*"—provided always they be not hypotheses as to modes of physical action for which experience gives no warrant.'[2]

[1] It should be noticed that Newton defined what he meant by 'hypotheses' when he said '*hypotheses non fingo*,' and that he did not object to what have now commonly (through the careless use of words) come to be regarded as hypotheses. Newton defined a hypothesis as whatever is not deduced from the phenomena.

[2] From a letter addressed by Sir J. Herschel to the present writer, August 1, 1869.

CHAPTER XII.

THE NEBULÆ: ARE THEY EXTERNAL GALAXIES?

IN the last chapter I have indicated reasons for believing that the sidereal system extends far beyond the range of the most powerful telescopes man has yet been able to construct. It need hardly be said that, supposing this view to be correct, we cannot possibly see any external galaxies unless they surpass our own many thousands of times in richness and splendour. Every analogy that we have for our guidance points to the conclusion that if our galaxy have limits, and there exist in space other galaxies, then those outer systems must be separated from ours by spaces exceeding the dimensions of the several galaxies many thousand or many million-fold in extent. We know that the distances separating the satellites from their primaries exceed in an enormous ratio the dimensions of the satellites. The distances separating the planets from each other exceed in an enormous ratio the dimensions of the planets. The distances separating our solar system from others enormously exceed the dimensions of the various solar systems. And we may conclude that in all probability the distances

separating our sidereal system from other similar systems in space must exceed in an enormous ratio the dimensions of our galaxy, and of all other such systems.

That the sidereal system has limits I do not doubt. Of course it *may* be co-extensive with space—that is, absolutely infinite in extent. But we have no reason for believing that in rising step by step, from system to system, until we have reached the highest class of system known to us, we have reached the real summit of that perhaps altogether limitless range of steps. We know, indeed, that if light do not suffer extinction in traversing space (and we have as yet no evidence that it does), the extent of the sidereal system *must* be limited, since otherwise the whole of the star-lit sky should shine with the brilliancy of sun-light.[1] And we

[1] This is, perhaps, obvious; but if not, the following proof may be accepted:—Let the whole of space be conceived divided into spherical shells, having our earth at the centre, the thickness of each shell being τ. Then taking two shells, one at a distance r, the other at a distance r' (both r and r' much greater than τ), we see that the number of stars in these shells will be proportional to $r^2\tau$ and $r'^2\tau$ respectively—that is, will vary as the product of the thickness of the shell and the square of its radius. (Here I am not concerned with those departures from uniformity which I have considered in the last chapter, because I suppose each shell large enough to include within it all varieties of distribution and aggregation. This applies also to what follows.) Now the average apparent size of the stars of one shell will be to the average apparent size of stars in the other in the inverse proportion of the respective radii of the shells, the intrinsic brightness of the light received from the stars of each set being equal. Thus the total amount of light from the stars of one shell is to the total amount of light from stars in the other as $r^2\tau \times \frac{1}{r^2} : r'^2\tau \times \frac{1}{r'^2} = 1 : 1$. Hence,

may carry this argument even farther. For, though the sidereal system should be limited, but other systems similar to it spread throughout the infinity of space, there would still result this ineffable blaze of light, surpassing the light of day as greatly as the vault of heaven surpasses the disc of the sun. And this again would be true, though this system of systems were limited in extent, but surrounded by similar systems of systems in the infinity of space. And so on, let the order of systems which finally becomes infinite in number be what it may. There is only one way to escape from this limitless series of system-orders—that is, by accepting as true the hypothesis that light suffers extinction as it voyages through space. But it is worth noticing, when we are actually dealing with the infinity of space, and when, therefore, limitless conceptions are not paradoxical, but in reality as available for our purposes as finite conceptions would be, that if we

supposing the amount of light received from one shell to be $\frac{1}{k}$th part of that which would be received if the whole celestial sphere were as bright as the sun's (that is, as a star's) disc—k being enormously large, the amount received from the other is also $\frac{1}{k}$th of this amount, and the total from all the shells must therefore be

$$\frac{1}{k}+\frac{1}{k}+\frac{1}{k}+\frac{1}{k} \quad . \; . \text{ to infinity.}$$

Now, by taking k terms of this series (or k shells out of our infinite series of shells) we should get unity, that is, the whole heavens lighted up with star-light or sun-light. There would be a proportion of stars in the same visual line, and so hiding each other; but since we can take 2 k, 3 k, or *infinity* times k if need be, there can be no doubt that the whole heavens would be lighted up with solar brightness. Compare next note.

do adopt the belief in an infinite succession of orders of systems; that is, first satellite-systems, then planetary-systems, then star-systems, then systems of star-systems, then systems of systems of star-systems, and so on to infinity; and if we accept as true of this infinite series what we know to be true of the part within our ken, viz. that the distance between the components forming any system is indefinitely great compared with the dimensions of these components, we no longer have as a conclusion that the whole heavens would be lighted up with stellar (that is, with solar) splendour; even though, in this view of the subject, there are in reality an infinite number of stars, just as in the view according to which the sidereal system extends without interruption to infinity.[1]

[1] It is clear that we no longer get, as in the previous note, a series of equal small terms. If we take our infinite series of shells as before we get for the sidereal system n times $\frac{1}{k}$ where n is finite, and therefore $\frac{n}{k}$ finite. We must indeed assume $\frac{n}{k}$ to be small, and so of other similar ratios presently to be dealt with. With respect to the system of systems, we have these considerations to guide us:—Any of the spherical shells within this system must supply to our skies an amount of light indefinitely less than one of the shells within the sidereal system itself, say, $\frac{1}{k'}$th part only, k' indefinitely large. But the number of shells falling within that system is very much greater, say, n' times as great where n' is finite. Therefore we get for the total amount of light coming from the system of systems a quantity proportional to $\frac{n\,n'}{k\,k'}$. And so for the system of system of systems we get a quantity proportional to $\frac{n\,n'\,n''}{k\,k'\,k''}$, where k'' is indefinitely large, n'' very large. And for each successive order we get a multiplier of the form $\frac{\text{N}}{\text{K}}$, where K is indefinitely

But whether we adopt this or any other view of the way in which external systems are arranged, this at

large, and K very large indeed. Suppose $\frac{\nu}{\kappa}$ to be the largest of all these multipliers, then the total amount of light received from the infinite system of systems is proportional to less than

$$\frac{n}{k}\left(1+\frac{\nu}{\kappa}+\frac{\nu^2}{\kappa^2}+\frac{\nu^3}{\kappa^3}\ .\quad .\text{ to infinity}\right),$$

(in which ν is supposed to be less than κ), *i.e.* to less than $\frac{n}{k}\left(\frac{\kappa}{\kappa-\nu}\right)$, a finite quantity—which will even be minute if k and κ are severally much greater than n and ν.

This particular mode of escaping from the difficulty suggested by the illumination of the heavens, without adopting the theory that light suffers extinction in its passage through space, occurred to me while I was preparing a series of papers entitled A New Theory of the Universe, which appeared in the 'Student' in the spring of 1869; and I there exhibit the considerations just dealt with. I was much pleased to find from a letter of Sir John Herschel's that the same idea had (probably earlier) suggested itself to him; and I was thus encouraged to believe that I had not gone very far astray in the whole series of papers, whereof the matter in question had seemed to me the most speculative portion. The following are the words in which Sir John Herschel expresses the ideas above dealt with:—'One of the arguments advanced in favour of the spatial extinction of light was that, if there is not such extinction, the whole heavens ought to be one blaze of solar light—admitting the universe to be infinite—because it was contended that there could then be no direction in space in which the visual ray would not encounter a star (*i.e.* a sun). This argument is fallacious, for it is easy to imagine a constitution of a universe literally infinite which would allow of any amount of such directions of penetration as *not* to encounter a star. Granting that it consists of systems subdivided according to the law that every higher order of bodies in it should be immensely more distant from the centre than those of the next inferior order—this would happen. Thus in our own, the moon is very near the earth, the satellites to their primaries. These primaries are immensely more distant from the sun, *their* centre; the fixed stars again still *more* immensely more remote from the sun. Suppose *our* system to terminate with the visible fixed stars; then imagine a system of such systems as remote from each other, *in comparison with their own dimensions*, as the distance

any rate is certain, that if the stars at the outer parts of our own sidereal system be beyond the ken of our most powerful instruments—and I have shown that there are strong reasons for this conclusion—then the component suns of external galaxies cannot by any possibility be visible. So that, according to this view, all resolvable nebulæ, at least, must be dismissed from the category of external galaxies. Nor will it be thought probable that irresolvable nebulæ are external galaxies, if once that view of the extent of the sidereal system is adopted.

But there are independent considerations on which I prefer now to dwell, for believing that all the nebulæ belong to the sidereal system.

It will hardly be necessary, let me remark in passing, for me to point out how this matter is associated with the subject of other worlds. It is true that when once it is admitted that there are external galaxies, it may be looked on as a matter of small importance (so far as the subject of this treatise is concerned) whether we can actually see those galaxies or not. I am not, for instance, in the same position as Dr. Whewell, who assigned to the nebulæ what I take to be their true place in the universe, with the express object of overthrowing the belief that there exist other galaxies as vast as the sidereal, or vaster, thronged with suns which are severally the centres of planetary systems, within which again are worlds as well suited to be the

of the fixed stars in comparison with the planetary system; such systems seen from each other would subtend no greater angle than a star seen from the sun—and so on.'

abode of life as this earth on which we dwell. But, though my purpose is different from his, it is equally necessary that I should insist on the true position of the nebulæ. Because, if these objects form indeed parts of the sidereal system, the relations they present are of extreme importance. They exhibit to us within the bounds of our galaxy systems altogether different from the solar system, and thus suggest ideas of other classes of worlds peopled with their own peculiar forms of life, as distinct perchance even in their general characteristics from any found amid the systems circling round stars, as the forms of life in Venus or in Mars must be in their special characteristics from those existing on our own earth.

Freed from those analogies which led the elder Herschel to regard the stellar nebulæ—resolvable and irresolvable [1]—as external star-systems, let us consider the relations presented by these and other nebulæ without reference to preconceived opinions.

We must first pay attention to one of the most striking of the discoveries which the spectroscope has yet enabled man to make—the discovery that certain nebulæ are gaseous. It is necessary to consider this significant discovery, rather than those which were the first to exhibit the real place of the nebulæ in our scheme, because we shall thus be able to divide the nebulæ at once into two great classes, instead of being

[1] By irresolvable stellar nebulæ I mean those nebulæ which, though not resolvable into stars, yet present the characteristic eatures which lead astronomers to believe that only increase of telescopic power is needed in order to effect resolution.

led to this arrangement by following out the history of those long processes of research by which the two great orders of nebulæ were long since separated from each other under the piercing scrutiny of Sir William Herschel.

The reader will see how the spectroscope could at once resolve a question which ordinary observations would be all but powerless to deal with. The nebulæ being self-luminous, the nature of the matter which is the source of their light would be shown by the character of the spectrum, as distinctly as though that matter were actually present in the laboratory of the spectroscopist.

Mr. Huggins thus describes the observation which first revealed the true nature of certain orders of the nebulæ. The object under examination was a nebula in Draco, belonging to the class of planetary nebulæ. 'On August 19, 1864, I directed the telescope armed with the spectrum apparatus to this nebula. At first I suspected some derangement of the instrument had taken place, for no spectrum was seen, but only a short line of light perpendicular to the direction of dispersion (that is, to what would in the case of solar light be the *length* of the spectrum). I then found that the light of this nebula, unlike any other extra-terrestrial light which had yet been subjected by me to prismatic analysis, was not composed of light of different refrangibilities, and therefore could not form a spectrum. A great part of the light from this nebula is monochromatic, and after passing through the prisms re-

mains concentrated in a bright line, occupying the position of that part of the spectrum to which its light corresponds in refrangibility. A more careful examination, however, showed that—a little more refrangible than the bright line, and separated from it by a dark interval—a narrower and much fainter line occurs. Beyond this, again, at about three times the distance of the second line, a third exceedingly faint line was seen. The positions of these lines in the spectrum were determined by a simultaneous comparison of them in the instrument, with the spectrum of the induction spark taken between electrodes of magnesium. The strongest line coincides in position with the brightest of the air-lines. This line is due to nitrogen.' . . . 'The faintest of the lines of the nebula agrees in position with a line of hydrogen.' The other bright line was not found to correspond with a known line of any terrestrial element. Besides the bright lines, an exceedingly faint spectrum was just perceived for a short distance on both sides of the group of bright lines. Mr. Huggins suspected that this was not uniform, but crossed by dark spaces. Subsequent observations on other nebulæ[1] induced him 'to regard this faint

[1] One of the most interesting of Mr. Huggins's researches into the subject of the light of nebulæ is his attempt to detemine its intrinsic brilliancy. By comparing the light of certain gaseous nebulæ with that of a sperm candle (of the size called 'six to the pound'), he found that these objects, assumed to be continuous, shine with a light varying in intrinsic brilliancy from the 1,500th to the 20,000th of that of such a candle. By a strange misconception, Mr. Lockyer, in discussing Mr. Huggins's result, speaks of the comparison as though it related to the absolute brightness of the

spectrum as due to the solid or liquid matter of the nucleus, and as quite distinct from the bright lines into which nearly the whole of the bright light from the nebula is concentrated.'

Thus was solved a problem which had, for the best part of a century, perplexed astronomers. There was not, indeed, a full answer to all the questions of interest associated with the problem. But it had been laid down by Sir William Herschel, as a legitimate conclusion from observation, that certain orders of the nebulæ are gaseous, and astronomers had ranged themselves for and against this proposition. Telescopic improvements had seemed at length to turn the scale in favour of those who held Sir William Herschel to have been mistaken. Already the problem had seemed all but definitely settled. And then in a moment this observation by Mr. Huggins had reversed the whole matter. It was now established beyond all possibility of future question that on the main point the greatest of modern astronomers had been altogether in the right.

The orders of nebulæ which give a spectrum of bright lines would seem from Mr. Huggins's observations to be (i.) the planetary nebulæ, (ii.) the ring nebulæ, (iii.) the irregular nebulæ. The spiral nebulæ

nebulæ, saying that 'such a candle a quarter of a mile off is 20,000 times more brilliant than the nebula.' Mr. Huggins's result is wholly distinct from this, and much more important. His comparison relates to the intrinsic luminosity of the nebular substance. not to the *quantity* of light received from the nebulæ. (The distance of the candle in Mr. Huggins's observations is not considered in the result; it was a mere matter of convenience.)

seem, for the most part, to give a continuous spectrum, but some of these objects give the bright line spectrum indicative of gaseity. The orders of nebulæ which give a continuous spectrum appear to be the following:—(i.) star groups, (ii.) clusters, regular and irregular, and (iii.) easily resolvable nebulæ. Of the irresolvable nebulæ a large proportion seem to be gaseous.[1]

Here, then, we find the nebulæ ranged into two important divisions, apparently separated by a distinct line of demarcation. Yet one is tempted to inquire whether these divisions may not in reality run into each other by the fact that among nebulæ of certain orders are objects belonging to both divisions. And the fact that beneath the bright-line spectrum of the gaseous nebulæ a faint continuous spectrum may be seen seems also to point in the same direction. We know that, so far as the telescopic appearance of the nebulæ is concerned, there is very striking evidence

[1] The following classification of nebulæ in this respect, by Lord Oxmantown, is interesting as indicating the results of observations made with so powerful an instrument as the great Parsonstown telescope (the 6-feet reflector).

	Continuous Spectrum	Gaseous Spectrum
Clusters	10	0
Certainly or probably resolved	5	0
Certainly or probably resolvable	10	6
Blue, or green, no resolvability	0	4
No resolvability detected	6	5
Total observed	31	15

Adding nebulæ not observed at Parsonstown, there are in all 41 which exhibited a continuous spectrum, and 19 which gave a spectrum indicative of gaseity.

of a gradual progression from clusters to irresolvable nebulæ; and therefore we are led to inquire whether the spectroscope conveys a similar lesson.

Now this question could only be answered satisfactorily by the observation of a series of nebulæ having spectra progressively varying, from bright lines on an almost invisible continuous spectrum to a continuous spectrum with the same bright lines superposed on it, but almost imperceptible, because their brightness so little exceeded that of the continuous spectrum. We have no evidence of such completeness. But Captain Herschel has observed in the southern heavens a clustering nebula with a continuous spectrum, on which he could just detect the three bright lines seen in the spectra of the gaseous nebulæ. So far as this evidence extends, the conclusion is obvious that the various orders of nebulæ are orders of but a single family. It will be seen presently that this conclusion, which is strikingly corroborated by other evidence, has a very important bearing on the views we are to form respecting the relations between the nebulæ and the sidereal system.

The first process by which we must attempt to form a correct estimate of the nebular system corresponds to Sir William Herschel's process of star-gauging. We must inquire according to what general laws the nebulæ are spread over the vault of heaven.

Now, when this is done, it appears that there is a well marked peculiarity in the arrangement of the nebulæ, a peculiarity as striking as the existence of

the galactic circle itself. *The nebulæ seem to withdraw themselves from the neighbourhood of the galaxy.* In the northern heavens they cluster very definitely towards the pole of the galaxy; in the southern they are arranged in streams and clustering aggregations, but the galaxy itself is, in either case, left almost clear of nebulæ.

If this peculiarity is accidental, the coincidence involved is most remarkable. Had there been a zone of nebulæ, and that zone had shown a tendency to coincidence with the Milky Way, the relation would have been thought strikingly indicative of a real association between the nebular and the sidereal systems. But is the direct converse of this relation more likely to be the effect of chance? Have not observers and experimenters concluded (in every other similar instance) that a law of contrast is as indicative of a real connection as a law of association? Is it not most surprising, therefore, that nearly all astronomers who have considered the relation in question have regarded it as affording strong evidence that the nebular system is wholly dissociated from the sidereal?

Next let us turn to special features. In the first place, let us inquire whether the different orders of nebulæ exhibit any peculiarities of arrangement.

We find that clusters exhibit a very marked preference for the neighbourhood of the Milky Way; resolvable nebulæ seem to prefer the galactic zone, but not in so decided a manner; and it is only among the irresolvable nebulæ that we recognise that withdrawal from

the Milky Way which had seemed characteristic of the whole nebular system before we considered its several orders. The fact that the irresolvable nebulæ form about four-fifths of the total number will account for the circumstance that a peculiarity really appertaining to that order alone should appear to belong to the whole system of nebulæ.

Again, the planetary and irregular nebulæ are found to affect the neighbourhood of the Milky Way. I have already mentioned that these objects are gaseous.

It is easy to see what general conclusions may be deduced from the peculiarities here touched upon. Obviously the first shows us most distinctly that there is a relation between propinquity to the Milky Way and the character of nebulæ as respects resolvability—a relation which points in the most decisive manner to the existence of a close association between the sidereal system of which the Milky Way certainly forms part, and the nebular system from which clusters and resolvable nebulæ cannot reasonably be separated. It is equally obvious that the second peculiarity indicates the existence of a close association between the Milky Way and the character of the nebulæ as respects gaseity; a relation which brings all the gaseous nebulæ into close association with the sidereal system, since we know that among the extra-galactic nebulæ there are many which are principally formed of the very same gases which appear in the irregular and planetary nebulæ. When we consider that those peculiarities of configuration and of constitution which have alike

seemed to indicate that the various orders of nebulæ merge into each other by indefinable gradations are both associated in a very distinct manner with the most marked peculiarity of the sidereal system, and when to this we add what has been already suggested by the relation of contrast between the irresolvable nebulæ and the Milky Way, the conclusion seems forcibly impressed upon us that the nebular and the sidereal systems are but different parts of one single scheme.

But I pass on to other evidence, independent of what has hitherto been adduced, and pointing with equal force to the same conclusion.

In the northern heavens it is not very easy to exhibit any general law of arrangement associating the nebulæ and the fixed stars. For reasons which yet remain to be detected, there are in fact many marked points of difference between the whole character of the heavens on the northern and on the southern side of the galactic zone. But even in the northern heavens one peculiarity has been remarked, which is well worthy of careful consideration. Sir William Herschel, while prosecuting his series of researches among stars and nebulæ, was struck by the circumstance that, after sweeping over a part of the heavens which was unusually barren, he commonly met with nebulæ; insomuch that it was his practice at such times to call to his assistant (his sister, Miss Caroline Herschel) to 'prepare for nebulæ.' This peculiarity was noticed also by Sir John Herschel.

Now what are we to understand by such a relation

as this? Can we suppose that, owing to some strange accident, external galaxies have been placed always opposite the barest regions of the sidereal system? Or, setting aside such a notion as obviously incredible, are we to imagine that when searching over those barren regions the astronomer has a better chance of detecting nebulæ than where stars are more richly strewn, because the sky is less filled with glare? We are forced to dismiss this notion that the barren regions of the heavens are thus in a manner the spy-holes of the sidereal system, by the fact (presently, and for another purpose, to be dwelt on more at length) that in the Magellanic Clouds, where stars of all magnitudes are richly strewn, nebulæ, even down to the very faintest orders, are more abundant than in any other region of the heavens. We have then no other conclusion to form, but that the association thus observed between starless regions and richness of nebular distribution indicates a very close relation indeed between stars and nebulæ; that, in fact, *the nebulæ in a sense represent the missing stars; that the region where those nebulæ appear has been drained of star materials, so to speak, in order to form them.*

In the southern heavens yet clearer proofs exist of an association between the stellar and nebular systems. We do not recognise in the northern skies any well-marked star-streams. In the southern skies, however, such streams have been recognised from the earliest ages. The constellations Hydra and Eridanus, the two streams from the Water-Can of Aquarius, and the

band between the Two Fishes,[1] indicate how clearly the ancients traced certain well-marked star-streams. The moderns have traced the extension of some of these streams in the constellations Grus, Hydra, Reticulum, &c. into the near neighbourhood of the southern pole. Now the nebulæ in the southern heavens exhibit a well-marked tendency to aggregate into streams. So that, in this mere resemblance between the general characteristics of the stellar and nebular systems in the southern heavens, we have a somewhat remarkable evidence of association. But when we consider the disposition of the two sets of streams—the stellar and the nebular—this evidence is very much strengthened. There is found to be a well-marked correspondence between the nebular and stellar streams, not merely as respects general position, but even in minute details—the nebular streams following the windings of the stellar ones. Such a relation would be very remarkable, even were it observed but in a single instance. Since, however, all the well-marked star-streams in the southern heavens are associated with well-marked nebular streams, no doubt can remain that the relation is not a mere coincidence, but indicates a real association between the nebular and stellar systems.

But yet more striking evidence remains to be considered.

[1] Though Pisces is not a southern constellation, yet it is south of the galactic circle, to which I am for the moment referring the constellations.

In the southern heavens there are two strange clouds of milky light, which have long been known by sailors as the Magellanic Clouds, but are commonly called by astronomers the Nubeculæ. Each of these objects, when examined with the telescope, is found to be constituted, like the Milky Way, of multitudes of small stars. But unlike the Milky Way, the Nubeculæ contain within their bounds many nebulæ of all orders. In fact, each of the Nubeculæ is at once a star-cluster and a cluster of nebulæ.

Now there can be no doubt whatever that the association here is not accidental, that we do not by some strange chance see a great star-cluster in the same direction as a much more distant and much vaster cluster of external galaxies. Nor again can there be any doubt that the generally circular figure of each Nubecula indicates a general approach to the spherical form in the case of each cluster. The probability that by some strange accident a cluster of cylindrical shape[1] might be so placed as to exhibit to us a circular figure is exceedingly small; but the chance that two such clusters should be presented in so exceptional a manner may be regarded as evanescent. We are compelled, then, to believe that, within the limits of spheres so placed as to subtend a small angle to the eye, stars of all magnitudes between the seventh and the twelfth inclusive are mixed up with nebulæ of all degrees of resolvability. 'Taking the

[1] Or, more correctly, a cluster shaped like a long frustum of a gigantic cone.

apparent semi-diameter of the Nubecula Major at three degrees,' says Sir John Herschel, 'and regarding its solid form as, roughly speaking, spherical, its nearest and most remote parts differ in their distance from us by a little more than a tenth part of our distance from its centre.' 'It must therefore be taken as a demonstrated fact,' he adds presently, 'that stars of the seventh and eighth magnitude and irresolvable nebulæ may co-exist within limits of distance not differing in proportion more than as nine to ten.' This demonstrated fact of Sir John Herschel's is the very fact to which I had been led by other considerations, the fact, namely, that the nebulæ are not external galaxies, but intimately associated with the sidereal system, of which, in fact, they form part and parcel. Dr. Whewell, accepting Sir John Herschel's reasoning as conclusive on the point, adopted the same view. And although Sir John Herschel himself, immediately after establishing this noteworthy conclusion, speaks respecting it in a tone of philosophic caution, it must not be forgotten that to his clear vision the association between nebulæ and fixed stars had presented itself as a demonstrated fact, and that even in the latest editions of his noble work on astronomy he has not altered the words in which he has spoken of that association.

Lastly, and perhaps most strikingly, the association between stars and nebulæ is indicated by the obvious connection between the figure of the irregular nebulæ and the arrangement of the star-groups seen in the same field of view. There is not one of the

irregular nebulæ which does not exhibit this peculiarity in the most striking manner. This may be asserted even of those nebulæ with respect to which Sir John Herschel has remarked that the arrangement may be accidental. His own pictures seem to me to prove in the most convincing manner that no such explanation can be accepted. The mere aggregation of a large number of stars in the very heart of a nebula might be an accident. The fact, for instance, that the great irregular nebula surrounding the star Eta Argûs agrees exactly in position with the greatest condensation of the wonderfully rich portion of the Milky Way on which that surprising variable lies, might be a mere coincidence, though in any case it would be a strange one. But when one examines the structure of this and similar nebulæ, and finds that the stars are arranged in a manner most obviously related to the arrangement of the nebular condensations (or folds as one may almost say), one cannot doubt that a real and intimate bond of association exists between the stars and the nebulous masses around them. If the extension of the milky light of the great Orion nebula to the star ι in the sword, which is centrally involved in strong nebulosity; to ε in the belt, which is similarly involved; and to several other stars in the constellation (all alike in occupying regions of increased nebular condensation), be a mere accidental coincidence, then the laws of probability had better be forgotten as soon as possible; for, as at present understood, they can only serve to lead men astray.

In the accompanying Plate is given a picture of the nebula Messier 17, as observed with Lassell's four-feet reflector at Malta. I have selected it as affording a very striking instance of the particular form of association I have just been dealing with. No one can, I think, refuse to recognise the fact that the system of stars shown in this drawing is not accidentally seen projected on a distant galaxy, but forms part and parcel of the nebula itself.[1]

The nebula around the strange variable star, Eta Argûs, already referred to, is another remarkable instance of this sort. More than two years ago I ventured to make two predictions about this object. The first was a tolerably safe one. I expressed my belief that the nebula would be found to be gaseous. After Mr. Huggins's discovery that the great Orion nebula is gaseous, it was not difficult to see that the Argo nebula must also be so. At any rate, this has been established by Captain Herschel's spectroscopic researches. The other prediction was more venturesome. Sir John Herschel, whose opinions on such points one would always prefer to share, had expressed his belief that the nebula lies far out in space beyond the stars seen in the same field of view. I ventured to express the opinion that those stars are involved in the nebula. Lately there came news from Australia that Mr. Le

[1] Sir John Herschel, referring to the accompanying Plate, expressed the opinion that the apparent association need not necessarily be real. The discovery of nebular tracts in the Pleiades has now practically demonstrated the validity of the opinion expressed in the text.

Sueur, with the great reflector erected at Melbourne, has found that the nebula has changed largely in shape since Sir John Herschel observed it. Mr. Le Sueur accordingly expressed his belief that the nebula lies *nearer* to us than the fixed stars seen in the same field of view. More lately, however, he has found that the star Eta Argûs is shining with the light of glowing hydrogen, and he expresses his belief that the star has consumed the nebulous matter near it. Without agreeing with this view,[1] I recognise in it a proof that Mr. Le Sueur now considers the nebula to be really associated with the stars around it.

Amongst other instances may be cited the nebula round the stars c^1 and c^2 in Orion. In this object two remarkable nebulous nodules centrally surround two double stars. Admitting the association here to be real (and no other explanation can reasonably be admitted), we are led to interesting conclusions respecting the whole of that wonderful nebulous region which surrounds the sword of Orion. We become certain that the other nebulæ in that region are really associated with the fixed stars there; that it is not a mere coincidence, for instance, that the middle star in the belt of Orion is involved in nebula, or that the lowest star of the sword is similarly circumstanced. It is a legitimate inference from the evidence that all the

[1] My belief is that as the star recovers its brilliancy observation will show that the nebula in its immediate neighbourhood becomes brighter (*not* fainter through being consumed as fuel). In fact, I am disposed to regard the variations of the nebula as systematic, and due to orbital motions among its various portions around neighbouring stars.

nebulæ in this region belong to one great nebulous group, which extends its branches to these stars. As a mighty hand this nebulous region seems to gather the stars here into close association, showing us, in a way there is no misinterpreting, that these stars and the nebula form one system.

It will be noticed, as respects the two proofs on which I have last dwelt, that they seem directly opposed to those which I first quoted. One cannot argue, it might be urged, that the nebulæ are associated with the sidereal system because they are least numerous where there are most stars, and *vice versâ*; while at the same time one draws the same conclusion from the aggregation of the nebulæ in streams or clusters where there are streams and clusters of stars, or from the fact that stars are seen actually mixed up with nebulous matter. At first sight this objection seems just; but, on consideration, it will be found that in reality, the two seemingly contrary lines of argument bear in the same direction. When we find the nebulæ gathered where stars are wanting, and *vice versâ*, we conclude that there is some reason for this peculiarity, and that that reason must involve some sort of association between the nebulæ and the stars; we see, further, that the relation is accounted for if we suppose that, in these cases, either the formation of nebulæ has drained a region of material from which single stars would otherwise have been formed, or *vice versâ*. Why, in a particular region, the formation of nebulæ should be encouraged, while the formation of stars should be

checked, we cannot say; nor can we account for the contrary peculiarity in another region: but we feel certain that some cause must exist for both relations, because the results are too marked to be due to accident. Now, in the case where we find both stars and nebulæ abundant in particular parts of the heavens, we feel equally certain that the result is not accidental. Even though there were not here, as in the former case, the evidence of a clearing of star-material from certain regions, we could not doubt that the association of stars and nebulæ was real, and not apparent. But in reality there is *here*, precisely as in the former case, a gathering together of stellar matter into certain regions. The very existence of such a stream as Eridanus or Hydra, and of such a cluster as the greater or lesser Magellanic Cloud, implies the action of such a process of segregation. A stream would not be recognisable if it were not bounded by relatively bare regions. Clusters like the Nubeculæ *might* be visible even on a rich sky—and were the sidereal heavens richly strewn with stars round these objects I should be disposed to admit that there was a difficulty in my theory. But what is the fact? Not only is each of the Nubeculæ placed in a region obviously bare of lucid stars, but Sir John Herschel, speaking of the telescopic aspect of the neighbourhood of these mysterious clusters, dwells again and again on its poverty. 'A miserably poor and barren region,' he says of one field near the Nubeculæ. 'The access to the Nubeculæ,' he says elsewhere, 'is on all sides through

a *desert.*' What evidence could more clearly point to the fact that these great clusters are gathered out from a vast region of space? Their internal structure teaches us how such a process of segregation leads to the birth of nebulæ as well as stars. The whole history of the sidereal system is indeed taught us in the Magellanic Clouds and the great streams of intermixed stars and nebulæ which flow towards them as rivers towards some mighty lake.

It remains that I should sum up the results which I have discussed in the last two chapters. It has seemed to many that my views tend largely to diminish our estimate of the extent of the sidereal system. The exact reverse is the case. According to accepted views there lie within the range of our most powerful telescopes millions of millions of suns. According to mine the primary suns within the range of our telescopes must be counted by tens of thousands, or by hundreds of thousands at the outside. What does this diminution of numbers imply but that the space separating sun from sun is enormously greater than accepted theories would permit? And this increase implies an enormous increase in the estimate we are to form of the vital energies of individual suns. For the vitality of a sun, if one may be permitted the expression, is measured not merely by the amount of matter over which it exercises control, but by the extent of space within which that matter is distributed. Take an orb a thousand times vaster than our sun, and spread over its surface an amount of matter exceeding

a thousand-fold the combined mass of all the planets of the solar system: so far as living force is concerned, the result is *nil.* But distribute that matter throughout a vast space all round the orb: that orb becomes at once fit to be the centre of a host of dependent worlds. Again, according to accepted theories, when the astronomer has succeeded in resolving the milky light of a portion of the galaxy into star, he has in that direction, at any rate, reached the limits of the sidereal system. According to my views, what he has really done has been but to analyse a definite aggregation of stars, a mere corner of that great system. Yet once more, according to accepted views, thousands and thousands of galaxies, external to the sidereal system, can be seen with powerful telescopes. If I am right, the external star-systems lie far beyond the reach of the most powerful telescope man has yet been able to construct, insomuch that perchance the nearest of the outlying galaxies may lie a million times beyond the range even of the mighty mirror of the great Rosse telescope.

But this is little. Wonderful as is the extent of the sidereal system as thus viewed, even more wonderful is its infinite variety. We know how largely modern discoveries have increased our estimate of the complexity of the planetary system. Where the ancients recognised but a few planets, we now see, besides the planets, the families of satellites; we see the rings of Saturn, in which minute satellites must be as the sands on the seashore for multitude; the wonderful zone

of asteroids; myriads on myriads of comets; millions on millions of meteor systems, gathering more and more richly around the sun, until in its neighbourhood they form the crown of glory which bursts into view when he is totally eclipsed. But wonderful as is the variety seen within the planetary system, the variety within the sidereal system is infinitely more amazing. Besides the single suns, there are groups and systems and streams of primary suns; there are whole galaxies of minor orbs; there are clustering stellar aggregations, showing every variety of richness, of figure, and of distribution; there are all the various forms of nebulæ, resolvable and irresolvable, circular, elliptical, and spiral; and lastly, there are irregular masses of luminous gas, clinging in fantastic convolutions around stars and star-systems. Nor is it unsafe to assert that other forms and varieties of structure will yet be discovered, or that hundreds more exist which we may never hope to recognise.

But lastly, even more wonderful than the infinite variety of the sidereal system is its amazing vitality. Instead of millions of inert masses, we see the whole heavens instinct with energy—astir with busy life. The great masses of luminous vapour, though occupying countless millions of cubic miles of space, are moved by unknown forces like clouds before the summer breeze; star-mist is condensing into clusters; star-clusters are forming into suns; streams and clusters of minor orbs are swayed by unknown attractive energies; and primary suns singly or in systems are

pursuing their stately path through space, rejoicing as giants to run their course, extending on all sides the mighty arm of their attraction, gathering from ever new regions of space supplies of motive energy, to be transformed into the various forms of force—light and heat, and electricity—and distributed in lavish abundance to the worlds which circle round them.

Truly may I say, in conclusion, that, whether we regard its vast extent or its infinite variety, or the amazing vitality which pervades its every portion, the sidereal system is, of all the subjects man can study, the most imposing and the most stupendous. It is as a book full of mighty problems—of problems which are as yet almost untouched by man, of problems which it might seem hopeless for him to attempt to solve. But those problems are given to him for solution; and he *will* solve them whenever he dares attempt to decipher aright the records of that wondrous volume.

CHAPTER XIII.

SUPERVISION AND CONTROL.

It is a peculiarity of the subject of other worlds than ours that it suggests more strikingly than any other certain difficulties in connection with conceptions as to supervision and control exercised over the universe.

Let us consider definitely (even though we must be unable to conceive clearly or at all) the infinities we have to deal with.

We know that space must be infinite. If the region amid which stars and nebulæ are scattered in inconceivable profusion be limited, if beyond lies on all sides a vast void, or if, instead, there be material bounds enclosing the universe of worlds on every hand, yet where are the limits of void or bound? Infinity of space, occupied or unoccupied, there must undoubtedly be. Of this infinity it has been finely said that its centre is everywhere, its boundary nowhere. Now, whether within this infinity of space there be an infinity of matter is a question which we cannot so certainly answer. Only, if we were to accept this as certain, that the proportion which unoccupied bears to occupied space cannot be infinitely great—a view

which at least seems reasonable and probable—then it would follow that matter as well as space must be infinite, since any finite proportion of infinity must itself also be infinite.

Time also must undoubtedly be infinite. If the portion of time which has hitherto been, or which will hereafter be, occupied with the occurrence of events (of whatever sort) were preceded and will be followed by a vast void interval, yet there can be neither beginning nor end to either of those bounding voids. Infinity of time, occupied or unoccupied, there must undoubtedly be. And though it is not possible for us to know certainly that there has been no beginning, or that there will be no end to that portion of time which is occupied with the occurrence of events (of whatever sort), yet it appears so unreasonable to conceive that unoccupied time bears an infinitely great proportion to occupied time that we seem led to the conclusion that occupied time is infinite—or, more definitely, that there has been no beginning and will be no end to the sequence of events throughout the infinitely extended universe.

Now to conceive of limits to the wisdom and power of One whose realm is infinite in extent and in duration is obviously to conclude that the ruler is infinitely incompetent to rule over His kingdom: for there can be no relation between the finite and the infinite save the relation of infinite disproportion.

Senses such as we have we can no more attribute to such a Ruler than we can assign to Him hands and

feet. Nor can we conceive in what way He can be cognisant of material processes which we only recognise through their material effects. Yet we can scarcely conceive of Him as other than cognisant of all those processes by which our senses can be affected.

But before considering the nature of such a Being's supervision of His universe, we may proceed a step further. The senses we possess are sufficient to indicate to us the possible existence of senses not merely far more acute, but of a wholly different kind. By the sense of touch, for instance, we can indeed recognise the feeling of heat; but it is easy to conceive of a sense (analogous to that by which light is made to teach us of the aspect of external objects) enabling men to judge of the figure, substance, internal structure, and other qualities of an object by the action of the heat-waves proceeding from it. Or again, electricity, instead either of light or of heat, might be the means of communicating intelligence as to the qualities of objects. We can conceive also of a sense bearing the same analogy to sight that the spectroscope bears to the telescope. And a hundred kinds of sense, or in other words, a hundred modes of receiving intelligence about what exists or is going on around us, might be readily conceived.

Yet once more, we know that reason is able to range beyond the action of the senses. Man is able to assure himself that events have happened which yet have produced no direct effect upon any of his senses. By the exercise of reason he becomes as well assured of

such events as though they had actually passed before his eyes. An analogous power, but infinite in degree, infinitely rapid in its operation, and infinite in the extent of space and time over which it ranges, we may conceive to be possessed by a true Ruler over the universe.

And now let us notice some of the conclusions to which these considerations tend.

Let us first deal with the teachings of that sense which is the most far-reaching[1] of all the faculties given to man—the sense of sight.

In a little treatise called 'The Stars and the Earth,' published anonymously several years since, some results of modern discoveries respecting light were dealt with in a very interesting manner. I propose to follow the path of thought indicated in that treatise, as a fitting introduction to wider conceptions of supervision and control over the universe.

We know from Römer's researches, and even more surely from the phenomenon termed the aberration of the fixed stars, that light does not travel with infinite velocity. Its speed is indeed so enormous that, compared with every form of motion with which we are familiar, the velocity of light appears infinitely great. In a single second light traverses a space equal to

[1] Most persons, if asked which sense comes next to sight in this respect, would answer hearing. Yet *touch*—or rather *feeling*—has a range far exceeding that of hearing, since we can feel the heat emitted by the sun. Nor is it difficult to conceive of such an increase in the delicacy of the sense of touch that even the minute amount of heat received from the fixed stars might be felt, and so the range of the sense extended many million-fold.

eight times the circumference of the earth; and therefore in travelling from any visible object on the earth to the eye of a terrestrial observer, light occupies a space of time indefinitely short. Yet even as regards such objects as these light has occupied a real interval of time, however minute, in reaching the eye; insomuch that we see objects not as they are at the moment we perceive them, but as they were the minutest fraction of a second before.

Raising our eyes from the earth to regard the celestial objects, we find, in place of the indefinitely minute interval before considered, a really appreciable space of time occupied by light in carrying to us information as to the condition of those distant orbs. From the moon light takes little more than a second and a quarter in reaching us; so that we obtain sufficiently early information of the condition of our satellite. But light occupies more than eight minutes in reaching us from the sun; a longer or shorter interval in travelling to us from Mercury, Venus, and Mars, according to the position of these planets; from about thirty-five to about fifty minutes in reaching us from Jupiter; about an hour and twenty minutes on the average in speeding across the great gap which separates us from Saturn; while we receive intelligence from Uranus and Neptune only after intervals respectively twice and three times as great as that which light takes in reaching us from the ringed planet.

Thus, if we could at any instant view the whole range of the solar system as distinctly as we see

Jupiter or Mars when in opposition, the scene presented to us would not indicate the real aspect of the solar system at that, or indeed at any definite instant. Precisely as a daily newspaper gives us a later account of what is going on in London than of events happening in the provinces, of these than of events on the Continent, and of these again than of occurrences taking place in America, Asia, Africa, or Australasia, so the intelligence brought by light respecting the various members of the solar system belongs to different epochs. If man had powers of vision enabling him to watch what is taking place on the different planets of the solar system, it is clear that events of the utmost importance might have transpired—under his very eyes, so to speak—while yet he remained wholly unconscious of their occurrence. Or, to invert the illustration, if an observer on Neptune could see all that is taking place on the earth, he might remain for hours quite unconscious of an event important enough to affect the welfare of a whole continent, though that event should happen under his eyes, and his visual powers be such as I have supposed. We can imagine, for example, an observer on Neptune watching the battle of Waterloo from the early dawn until the hour when Napoleon's heart was yet full of hope, and our great captain was watching with ever-growing anxiety, as charge after charge threatened to destroy the squares on whose stedfastness depended the fate of a continent. We can conceive how full of interest that scene would have been

to an intelligent Neptunian, and how eagerly he would have watched the manœuvres of either army, and also, what neither army knew of, the approach of Blucher with his Prussians. Yet, while our Neptunian would thus have traced the progress of the battle from his distant world, the conflict would in reality have been long since decided, the final charge of the British army accomplished, the Imperial Guard destroyed, Napoleon fugitive, and the Prussians, who to the Neptunian would be seen still struggling through muddy roads towards the field of battle, would have been relentlessly pursuing the scattered army of France.

It is, however, when we pass beyond the limits of the solar system that the non-contemporaneous nature of the scene presented to us becomes most striking. Here we have to deal not with seconds, minutes, or hours, but with years, decades, and centuries. From the nearest of the fixed stars light takes fully three years in travelling to the earth. Even the star 61 Cygni is so far from us that its light only reaches us in seven years. And so far as observation has hitherto gone, it seems unlikely that amid the whole host of heaven there are so many as a hundred stars—lucid or telescopic—whose light reaches us in a shorter interval of time than twelve or fifteen years. Whatever views we form as to the arrangement of the sidereal scheme, whether those usually accepted be held to be correct, or whether I have been right in adopting others, there can be no doubt that, amongst the stars revealed to us by the telescope, there must be myriads

which lie many times farther from us than the bright star in Centaurus and the orb in Cygnus which have been found relatively so near. In fact, the views I have adopted respecting the wide range of magnitude among the fixed stars do not interfere in the least with the theories which have been formed as to the distances from beyond which the light of some of the stars, only just visible in powerful telescopes, must be supposed to reach us. On the contrary, one may conceive, according to my views, that some of these faintly seen orbs may be many times larger even than giant Sirius, in which case the distance of such stars would be many times greater than has been hitherto supposed. W may certainly assume with confidence that many stars only visible in powerful telescopes shine from beyond depths which light would occupy thousands of years in traversing. I cannot, indeed, go farther, as astronomers have hitherto done, and say that the nebulæ must be regarded as external galaxies, and therefore as sending their light to us over spaces which light must take many times as long an interval in traversing as it does in travelling to us from the bounds of our own galaxy. But it would be to misinterpret altogether the views which I have formed respecting the universe to suppose that I imagine those distant spaces which astronomers have hitherto filled with imaginary galaxies to be untenanted. On the contrary, I have no doubt whatever that galaxies resembling our own exist at distances infinitely exceeding those at which astronomers have placed their

most distant nebular universes, if even the bounds of our own galaxy do not extend into space as far as the widest limits hitherto assigned to the system of nebulæ. So that I am not precluded from speaking of orbs whose light, though unrecognised by us, is yet ever pouring in upon the earth, conveying, in letters we cannot decipher or even trace, a message which has taken millions on millions of years in traversing the awful gulf beyond which lie those mysterious realms.

If we conceive, then, that man's visual powers could suddenly be so increased that, without instrumental aid, he could look around him into the celestial depths, piercing even to those outer galaxies which astronomers have seen only imaged in the nebulæ, how wide would be the range of time presented to him by the wonderful scene he would behold! There would blaze out Alpha Centauri with its record three years old; there the star in Cygnus as it existed seven years since; the whole host of stars known to man would exhibit records ranging from a few years to many centuries in age; and lastly, the external galaxies, which are perhaps for ever hidden from the searching gaze of man, would reveal themselves as they were ages on ages before man appeared upon the earth, ages even before this earth was framed into a globe, nay, ages perhaps before the planetary system had begun to gather into worlds around its central orb.

It is when we are thus contemplating in imagination the whole expanse of the universe, and as one almost may say the whole range of past time, that the

author of the little treatise I have spoken of invites us to consider two processes of thought having sole reference to this earth on which we live, and to that history which, though all-important to ourselves, seems to fade into such utter insignificance in the presence of the grand history of the orbs which lie in uncounted millions around us.

To a being placed on some far distant orb, whence light would occupy thousands of years to wing its flight to us, there would be presented, if he turned his gaze upon our earth, and if his vision were capable of telling him of her aspect, the picture of events which thousands of years since really occurred upon her surface. For the light which left the earth at that time, winging its way through space with the account, if we may so speak, of those occurrences, is now travelling as swiftly as when it left our earth, but amid regions of space removed from us by a light-journey thousands of years in duration. And thus, to the observer on this distant orb, the events which happened in the far-off years would seem to be actually in progress.

But now conceive that powers of locomotion commensurate with his wonderful powers of vision were given to this being, and that in an instant of time he could sweep through the enormous interval separating him from our earth, until he were no farther from us than the moon. At the beginning of that tremendous journey he would be watching events which were occurring thousands of years ago; at its close he would gaze upon the earth as it was one second only before

he undertook his instantaneous flight; so that, in the course of his journey, he would gaze upon a succession of events which had occurred during those thousands of years upon the face of this little earth.

The other conception is no less beautiful and striking —I may remark, also, that it is, in a scientific sense, somewhat more exact. Suppose that a being armed with such powers of vision as we have imagined should watch from the neighbourhood of our earth the progress of some interesting event. If he then began to travel from the earth at a rate equal to that at which light travels, he would see one phase of the event continually present before him, because he would always be where the light-message recording that event was actually travelling. By passing somewhat less swiftly away, he would see the event taking place with singular slowness; while passing away more swiftly, he would see the event occurring in inverted order. Suppose, for example, he was watching the battle of Waterloo—he could gaze on the fine picture presented by the Imperial Guard as they advanced upon the English army, for hours, years, nay, for centuries or cycles; or he might watch the whole progress of the charge occurring so slowly that years might elapse between each step of the advancing column, and the bullets which mowed down their ranks might either seem unmoving, or else appear to wend their way with scarcely perceptible motion through the air; or finally, he might so wing his flight through space that the Guard would seem to retreat, their dead men coming

to life as the bullets passed from their wounds, until at length the Old Guard would be seen as it was when it began its advance, in the assured hope of deciding Waterloo, as it had already decided so many hard-fought battles for its Imperial Chief.

It may seem hypercritical to notice scientific inexactness in ideas professedly fanciful. But as the author lays some little stress upon the scientific truth of the method in which his fancies are exhibited, and as, further, he dwells upon two of the more obvious objections to the first conception, it may be well to consider a further objection, which enforces on us a total change in the way of presenting the idea. He remarks that the being he has conceived to be borne towards the earth through a distance so enormous would not see in a moment the whole history of the earth during the thousands of years considered, but only the history of that hemisphere which was turned towards him; while, further, all that took place under roofs or under cover of any sort would remain unperceived by him. But there is a more serious objection. Amongst the events which have taken place during those thousands of years have been thousands of revolutions of the earth around the sun, and more than 365 times as many rotations of the earth upon her axis, to say nothing of the stately sway of the earth in her motion of precession. So that our imaginary observer would in reality see the earth whirling with inconceivable rapidity upon its axis, and sweeping with even more tremendous velocity around the sun, so as to complete

thousands of circuits in a single second. He would see clouds forming and vanishing in an amazing succession of changes, all occurring in a single instant. And even though his powers of vision enabled him to pierce the cloud-envelope, he would not have a consecutive presentment of the various events occurring in any part of the earth, but only a haphazard succession of half days for each portion of her surface.

However, we can easily see that, by a slight modification, the beautiful conception of our author can be made to illustrate one mode at least in which the events occurring upon our earth may be conceived to be at all times present to the thoughts of an Omnipresent Being. Imagine a sphere with a radius over which light would travel in the time which has elapsed since living creatures first began to move upon this earth, and having for centre the place occupied by the earth at that instant. Then, if we imagine millions of eyes over the surface of that sphere, all turned with piercing powers of vision upon the central earth, we see that to these eyes the earth would be presented by the record of light, not as she is now, but as she was at that primæval day. Now, conceive those millions of eyes closing swiftly in upon the earth, but with this peculiarity of movement, that, instead of being always on a sphere around a fixed point, they were always on a sphere around the position which was really occupied by the earth when the light-messages started which those eyes were receiving at the moment. Then if that wondrous sphere con-

tracted in an instant, according to the law assigned it, until its myriad millions of eyes were gazing intently on our earth from a sphere of but a few thousand miles in radius, the whole history of the earth, so far as light could render it, would have been in a moment of time presented before the myriad-eyed sphere.

By extending these considerations to other modes in which the history of an event is recorded, so to speak, by natural processes, we can see that a much more complete and definite picture of past events than light can convey must be at all times present in the universe. A sense which could analyse heat-impressions as eyesight analyses light, would tell us not only what eyesight tells us, but much that no light-messages can convey to us. At least it is conceivable that a sense of this sort would enable the being provided with it to recognise not merely the nature of the surface of any body whose heat reached the organ of this sense, but the quality of the body's internal structure, processes going on within the body, or the nature of bodies so placed that eyesight would not render us sensible even of their existence. Electricity, in like manner, would avail to give information altogether distinct from that which light can impart.

But again, the senses by which we judge of what is going on around us are after all merely certain means by which we judge of causes by their effects. When we say, for instance, that we have seen such and such an object, or watched such and such an event, what we really imply is that we have recognised certain physical

impressions which we can only explain by the existence of that object, or by the occurrence of that event. We know, in fact, that in certain exceptional cases impressions resembling those caused by the actual presence of an object, or by the actual occurrence of some event, may arise where no such object has been present, or where no such event has taken place. till, we commonly feel safe from error in concluding from certain impressions conveyed to the mind by the agency of the senses that certain objects have been really present, at rest or in action, before us.

But then, even man, limited as are his powers, can yet follow a series of effects and causes far more numerous than those concerned in the act of vision; and so he can become certain of the occurrence of past events of which no sense he possesses gives him any direct information. For example, though I neither saw the battle of Waterloo nor heard the thunder of the guns there, yet I am as certain that the battle really took place as though sight and hearing had given me direct information on the matter. And when I inquire whence that certainty arises, I find a complicated series of events involved in my acquisition of the knowledge that the battle took place. My interpretation of the letterpress account of the battle involved in itself a number of more or less complex relations, associated with the question of my confidence in those who taught me that certain symbols represented certain letters, that certain com-

binations of letters represented certain words, and that certain words represented certain ideas. Not to follow out the long train of thoughts thus suggested, it will be clear that, with regard to a variety of matters, the knowledge which any man has is associated with considerations of cause and effect, of general experience, of confidence in the accounts of others or in his own judgment, which are in reality of a highly complex character.

Now, we are led by these thoughts to remember that independently of those records of past events which are continually present throughout the universe in processes resembling those which directly affect our senses, such events leave their record (even to their minutest details) in the consequences to which they have led. If a great naturalist like Huxley or Owen can tell by examining the tooth of a creature belonging to some long extinct race, not only what the characteristics of that race were, but the general nature of the scenery amidst which such creatures lived, we see at once that a single grain of sand or drop of water must convey to an Omniscient and Omnipresent Being the history of the whole world of which it forms part. Nay, why should we pause here? The history of that world is in truth bound up so intimately with the history of the universe that the grain of sand or drop of water conveys not only the history of the world, but with equal completeness the history of the whole universe. In fact, if we consider the matter attentively, we see that there cannot be a single atom throughout space which could

have attained its present exact position and state, had the history of any part of the universe, however insignificant, been otherwise than it has actually been, in even the minutest degree.

Turning from the past to the future, we must not let the limited nature of our recognition of the course of future events prevent us from forming a just opinion as to the way in which the future is in a sense always present. We can judge of the past by its effects, but we are almost utterly unable to judge of the future by its causes. Yet we cannot doubt that the future is present in its germs, precisely as the past is present in its fruits. It may be regarded in fact as merely a peculiarity of man's constitution that the past is more clearly present to his mental vision than the future. It is easy not only to conceive that the future and the past should be equally present to intelligent creatures, but to conceive of a form of intelligence according to which past events would be obliterated from the mind as fast as they took place, while the future should be as actually present as to the ordinary human mind the past is.

In considering the Omniscient Omnipresent Being, however, all questions of degree must be set on one side. The future must be absolutely and essentially present to such a Being in its germs as the past has been shown to be in its fruits. If a grain of sand contains in its state, figure, and position, the picture of the universe as it is, and the whole history of the universe throughout the infinite past—and who can doubt that

this is so?—it contains with equal completeness the history of the universe throughout the infinite future. No other view is compatible with the assumption of infinite wisdom, and no assumption which limits the wisdom of a Ruler of an infinite universe is compatible with our belief in the fitness of such a Ruler to reign supreme over the universe.

Obviously also every event, however trifling, must be held to contain in itself the whole history of the universe throughout the infinite past and throughout the infinite future. For every event, let its direct importance be what it may, is indissolubly bound up with events, preceding, accompanying, and following it, in endless series of causation, inter-action, and effect.

So far, then, as the supervision of a Ruler over the universe is concerned, we have two lines of thought, each leading to the recognition of perfect supervision. In virtue (1) of the omnipresence, and (2) of the infinite wisdom of such a Ruler, He could see at each instant the whole universe as it has been in the infinite past, as it is now, and as it will be in the infinite future; and this being as true of any one instant as it is of any other, we recognise the operation of yet a new form of infinity—the infinite duration of the Ruler's existence—to render yet more inconceivably perfect His supervision of the universe.

With regard to control it need hardly be said that if a Ruler does exercise control, apart from the laws assigned to His universe, His knowledge of the progress of past and future events would not therefore be